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ITR-1438

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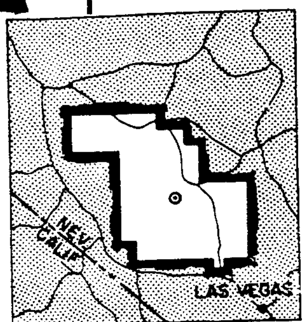
PRELIMINARY REPORT

# OPERATION PLUMBBOB




NEVADA TEST SITE

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## Project 6.4

## ACCURACY AND RELIABILITY OF A SHORT-BASELINE NAROL SYSTEM

Classification [redacted] (Changed to [redacted] ATOMIC ENERGY ACT 1954

By Authority of DASA SC-3 Memo 11/30/61

By E. Nelms Date 4 Dec 61

HEADQUARTERS FIELD COMMAND,
ARMED FORCES SPECIAL WEAPONS PROJECT
SANDIA BASE, ALBUQUERQUE, NEW MEXICO

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This is a preliminary report based on all data available at the close of this project's participation in Operation PLUMBBOB. The contents of this report are subject to change upon completion of evaluation for the final report. This preliminary report will be superseded by the publication of the final (WT) report. Conclusions and recommendations drawn herein, if any, are therefore tentative. The work is reported at this early time to provide early test results to those concerned with the effects of nuclear weapons and to provide for an interchange of information between projects for the preparation of final reports.

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This document consists of 1 page
No 201 of 240 copies, Series A
(Distribution Same as for ITR-1438)

March 31, 1960

# ERRATA SHEET for ITR-1438

ACCURACY AND RELIABILITY OF A SHORT-BASELINE NAROL SYSTEM
(OPERATION PLUMBBOB PRELIMINARY REPORT, PROJECT 6.4)

Note. The ITR-1438, with the corrections shown below, is considered the final report of Plumbbob Project 6.4—no WT report will be issued.

1. Page 14, line 3. FOR: the maximum Narol-fix error = (Max LOP error) ÷ (sin $^1/_2$ LOP angle). READ: the maximum Narol-fix error = (Max LOP error) $\dfrac{\sqrt{2 + 2\,|\cos \text{LOP angle}|}}{\sin \text{LOP angle}}$

2. Page 24, Table 2.1. FOR: Distance to NTS, Nautical miles. . . READ: Distance to NTS, Statute miles.

3. Page 26, Figure 2.6. Insert letter D under left-hand scope trace. Legend: FOR: B—recorded dashes at rate of 0.1 per second and dots at the rate of 0.01 per second; READ: B—recorded dashes at the rate of one dash per 0.1 second and dots at the rate of one dot per 0.01 second;

4. Page 28, Table 3.1. On NTS World Time, Shot Morgan FOR: 0600:59.064 READ: 0600:00.064.

5. Page 29, Table 3.3. The following are more accurate yields for the "Events" named:

| Shot | Yield kt |
|---|---|
| Wheeler | 0.195 |
| Franklin′ | 4.7 |
| Laplace | 1.22 |
| Morgan | 7.8 |

6. Page 32, legend for Figures 3.2 and 3.3. FOR: D—recorded dashes at rate of 0.1 per second and dots at the rate of 0.01 per second; READ: D—recorded dashes at the rate of one dash per 0.1 second and dots at the rate of one dot per 0.01 second;

7. Pages 33 through 36, Figures 3.5 through 3.10. No attempt should be made to use these curves unless the shots listed in Erratum 5 are replotted, using the corrected yields. Shots Newton and Fizeau have been plotted incorrectly also.

8. Add the following references:

9. H. Hoogasian; "Narol System Data Analysis"; Final report, Contract AF19(604)-2148; Raytheon Manufacturing Company.

10. R.A. Nelson and P.D. Marr; "Waveform and Sferics Study (U)"; Final report, Contract AF19(604)-2283, March 1959; Stanford Research Institute.

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ITR–1438

OPERATION PLUMBBOB—PROJECT 6.4

# ACCURACY AND RELIABILITY OF A SHORT-BASELINE NAROL SYSTEM

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Issuance Date: March 3, 1958

[redacted]

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This material contains information affecting the national defense of the United States within the meaning of the espionage laws, Title 18, U.S.C., Secs. 793 and 794, the transmission or revelation of which in any manner to an unauthorized person is prohibited by law.

H Black

H. Black, Lt Col, USA
Director, Program 6

K.D. Coleman

K. D. Coleman, Col, USAF
Test Group Director, Programs 1–9



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# ABSTRACT

The primary objectives of this Indirect Bomb Damage Assessment (IBDA) experiment were to incorporate results of Operation Redwing into an operational-type short-baseline Narol system and to study the reliability and accuracy of the system as a function of yield, range, type of propagation paths, and lightning-transient interference.

Narol nets, each consisting of two unmanned slave stations and one manned master station, were established at Albuquerque, New Mexico, Vale, Oregon, and Rapid City, South Dakota. Forty-three lines of position (from a possible 49) were obtained having average errors of 0.5 nautical miles for the Albuquerque net, 0.4 nautical miles for the Vale net, and 0.8 nautical miles for the Rapid City net. These lines of position gave fixes having an average error of 0.8 nautical miles. In general, the times of detonation were measured with an error of less than 10 milliseconds.

Lightning transient data were recorded and analyzed throughout the test series at various times of the day. In general, it was found that there were no consistent patterns peculiar to the waveforms, field strengths, or pulse durations of these transients that would distinguish them from the electromagnetic pulse of a nuclear detonation.

To speed data reduction and analysis, an area-gating system was tested. With this system, the film records of electromagnetic transients originating within a 10-mile radius of the detonation were marked electronically, thereby reducing the amount of data that had to be analyzed.

The area-gating system was tried on six shots. On each, data were collected for about one-half hour, and the area-gating system correctly marked the record for concurrent identification and analysis. With the record so marked, operators were able to select the correct pulse, analyze it, and report the fix and detonation time in less than fifteen minutes.



[redacted]

# FOREWORD

This report presents the preliminary results of one of the 43 projects comprising the Military Effects Program of Operation Plumbbob, which included 28 test detonations at the Nevada Test Site in 1957.

For overall Plumbbob military-effects information, the reader is referred to the "Summary Report of the Director, DOD Test Group (Programs 1–9)," ITR–1445, which includes: (1) a description of each detonation, including yield, zero-point location and environment, type of device, ambient atmospheric conditions, etc.; (2) a discussion of project results; (3) a summary of the objectives and results of each project; and (4) a listing of project reports for the Military Effects Program.

# PREFACE

A large part of the data analysis included in this report was accomplished by Mr. Harry Hoogasian of the Raytheon Manufacturing Company.

# CONTENTS

FIGURES





[redacted]

TABLES





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# Chapter 1

# INTRODUCTION

## 1.1 OBJECTIVE

The overall objective of the Air Force Cambridge Research Center's (AFCRC) Narol IBDA program is to study the feasibility of using the electromagnetic signals radiated from a nuclear detonation to determine its ground-zero position and yield at locations of 200 to 5,000 miles from the source.

On Operation Plumbbob, the specific objective was to determine the accuracy and reliability of a Narol system as a function of range. In addition, it was desired to investigate methods of isolating the electromagnetic pulse of a nuclear detonation from lightning transients and to collect data on the nature of bomb pulse distortion resulting from overland propagation.

## 1.2 BACKGROUND

During Operation Buster-Jangle, it was discovered that electromagnetic energy is radiated from a nuclear detonation. Measurements of this radiation were made in subsequent tests by the National Bureau of Standards for AFOAT-1 and by AFCRC (References 1, 2, and 3).

To fulfill the Air Force IBDA requirements set forth in the ARDC Operational Requirement Number 59, "Atomic Strike Recording System," dated 18 April 1955, AFCRC implemented the Narol IBDA program and conducted field tests during Operations Teapot, Redwing, and Plumbbob. The overall mission of this program was to develop a system that would rapidly detect and locate atomic strikes on a global basis. After development, the Atomic Strike Recording System could be employed to detect and locate nuclear detonations in U. S. military operations against enemy nations. In addition, the system or a part thereof could be utilized to determine the location of enemy atomic strikes and to estimate damage to areas within the zone of interior or friendly territories.

The selection of the Narol (inverse Loran) direction-finding technique to meet this requirement led to three areas of investigation: (1) the potential resolution of ground-zero fixes using the electromagnetic bomb pulse; (2) the isolation of the bomb pulse from lightning-transient static; and (3) the feasibility of developing operational equipment capable of giving useful fix resolutions within the 30-minute reporting time established by the ARDC Operational Requirement Number 59.

During Operation Teapot, a propagation experiment was conducted to determine whether inverse-Loran potential fix resolutions were sufficiently accurate to warrant further development of a Narol system. The pulse-cycle-matching technique was used successfully to measure time-of-arrival differences with microsecond resolution, and fixes were obtained for each event with suitable accuracy for an operational system.

A short-baseline Narol system was then designed and tested for fix resolution and operational feasibility during Redwing. Useful lines of position were obtained with this



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system at ranges of 2,000 and 4,000 miles. After each shot participation, the lines of position and detonation time were reported to the Program Director within a half hour, but alerts giving the exact predicted shot times were required to isolate the bomb pulse from atmospheric noise.

## 1.3 THEORY

As a means of determining navigational fixes, the theory of relative time of arrival of electromagnetic pulses has been developed thoroughly for the use of standard Loran (see Reference 6). Narol, an inverse Loran system, operates on the theory that the velocity of electromagnetic propagation is essentially constant and that the difference in propagation time of the bomb pulse from its origin over two paths is a measure of the difference in length of the two paths. The time interval from the arrival of the pulse at one receiver to its arrival at another receiver is a measure of the amount by which the detonation range from the latter receiver exceeds the range from the former. This difference in range is precisely the constant that defines a hyperbola with respect to the two receivers. Therefore, the time interval between reception of the bomb pulse at two receiving stations locates the detonation point upon a hyperbolic line of position that passes between the receivers and is concave towards the receiver nearest the detonation point. The intersection of two such hyperbolic lines of position determines the point of detonation (Narol-fix).

Measurement of the time interval between reception of the bomb pulse at the two receivers (relative time of arrival) requires comparing the time of arrival of the pulse at each receiver with a relative time reference synchronized to a timing system that gives the desired accuracy of resolution. Two methods of accomplishing the measurement are (1) retransmission of the bomb pulse from the two receiving stations to a central master station where the measurement is made by taking into account the equipment and propagation time delays, and (2) transmission of a time reference to the receiving stations where independent measurements are made and then compared, taking into account the equipment and propagation time delays. Use of the first method requires a wide-band line-of-sight microwave system which consequently limits the length of the baseline between the receiver stations. The second method permits use of none-line-of-sight long baselines, but requires a more-complicated operative process to accomplish the data analysis.

Figures 1.1 and 1.2 illustrate possible geometries for short- and long-baseline Narol systems. At each three-station net in the short-baseline system, the bomb pulse is received at the slave stations and retransmitted to the master station for time-of-arrival analysis to obtain a line of position. In the long-baseline system, time-of-arrival analysis is done at each receiving station with respect to the time reference, and the data are compared to get the time difference required to establish the lines of position.

The performance characteristics of an operational Narol system depend on (1) anomalies—which determine the potential ground-zero fix resolution—in the physical phenomena governing the creation and propagation of the pulse to the various receivers, (2) the ability to identify and isolate the bomb pulse from lightning transients, (3) the ability of the equipment to measure the difference in pulse time of arrival with accurate time resolution, and (4) limitations placed on the equipment as a result of established criteria for reliability, maintenance, and operating personnel.

1.3.1 Potential Ground-Zero-Fix Resolution. The Narol-fix error is a function of the individual hyperbolic line-of-position (LOP) errors and the angle of intersection of the lines of position (LOP angle). If it is assumed that maximum LOP errors are the

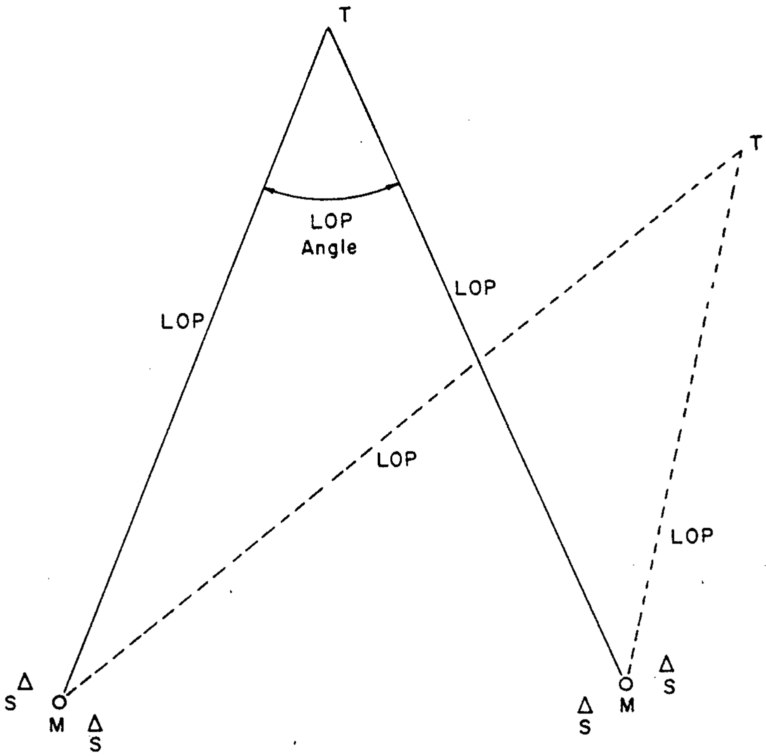


Figure 1.1 Short-baseline Narol geometry.
M, master station; S, slave station; T, possible target.

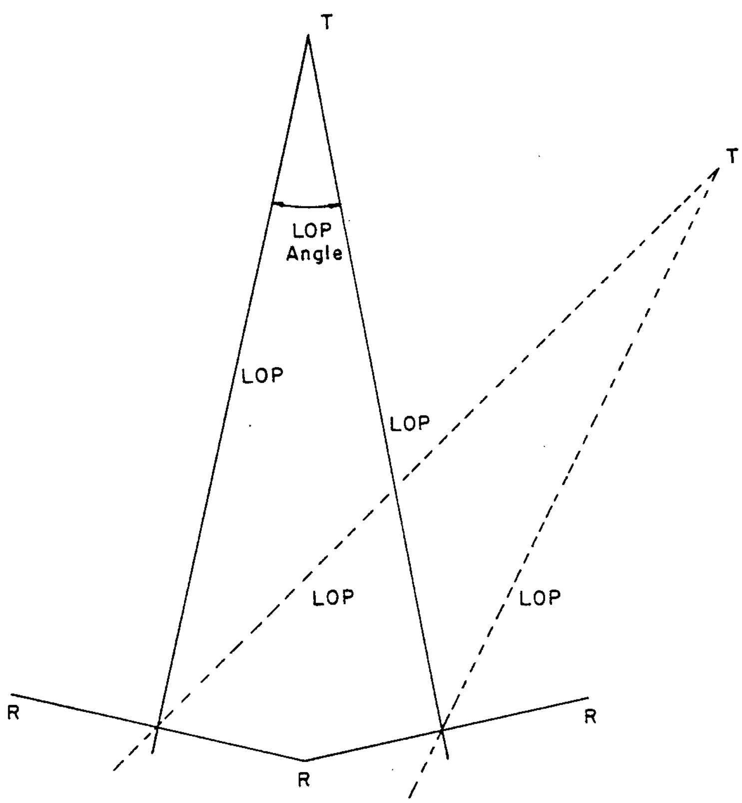


Figure 1.2 Long-baseline geometry.
R, receiving stations; T, possible target.



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same for any two LOP's, that the LOP's are straight lines over a small area in the vicinity of the target, and that the LOP angle is less than 90 degrees, then (from Figure 1.3) the maximum Narol-fix error = (Max LOP error) ÷ (sin $\frac{1}{2}$ LOP angle). Thus, it is

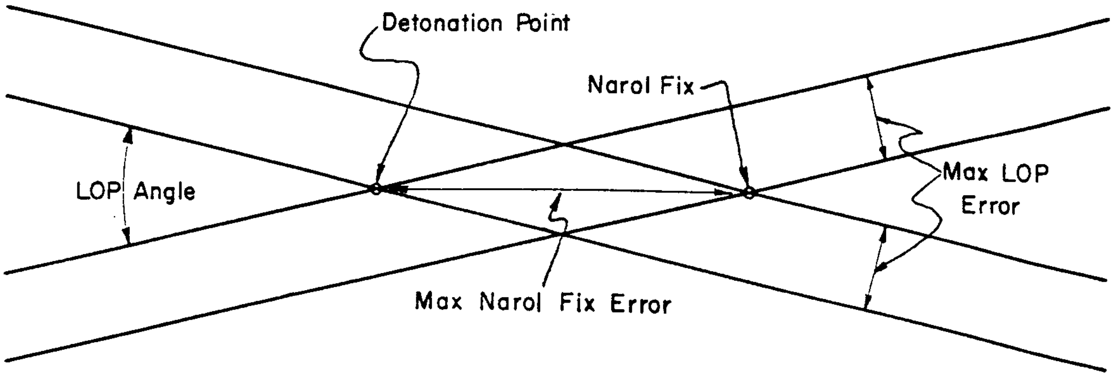


Figure 1.3 Maximum fix error.

possible to select the two slave sites of a short-baseline Narol system to have LOP angles approximating 90 degrees and obtain minimum Narol-fix errors.

The LOP errors are a function of the distance between receivers (baseline), the angle between the baseline and a line to the target, and the errors in measuring relative time of arrival. The errors in measuring relative time of arrival result from propagation anomalies along the various paths from the detonation to the receiving stations, human errors, and instrumentation errors.

1.3.2 Propagation Errors. Propagation errors are those resulting from the anomalies in electromagnetic-propagation phenomena that system geometry may minimize but equipment improvement cannot correct. The frequency composition of a bomb pulse covers a wide range, and its peak field strength varies with distance, as illustrated in Figure 1.4. Furthermore, the pulse, when received at a distance from its source, is comprised of a ground wave mixed with several sky-wave modes of propagation. The variation with distance of field strength and phase relation of the various frequency components, and the presence or absence of the different propagation modes cause the shape of the wave to vary with distance, as illustrated in Figure 1.5. Because the character of the pulse is sufficiently dissimilar at various ranges, it is impossible to match individual cycles and quite difficult to match the envelope unless the receiving stations are at approximately the same distance from the detonation point.

If the receiving stations are at the same distance from the detonation, there are minor variations in the recorded wave forms caused by variations in propagation velocity and frequency-component degradations along the paths from the detonation point to the receivers. Some distortion also results because the propagation-path lengths for the sky-wave modes vary with variances in the height of the ionosphere at points of incidence.

Waveform time-of-arrival analysis of one type or another is required for any Narol fix. Since the duration of the ground-wave pulse is about 60 microseconds and since fractional-microsecond relative time-of-arrival resolution is required, the received signals must have close-to-identical frequency components for accurate analysis. In practice, this has required filters with a bandpass from 5 to 100 kc. Operationally such a bandwidth is feasible in the presence of normal background noise if the field strength of the bomb pulse is at least 0.25 volts/meter (center to peak) at the receiver sites.

In general, errors due to differences in range and propagation paths decrease as the paths become more nearly identical. This condition is approached as the Narol baseline

length decreases. Therefore, the propagation errors will be smaller on a short-baseline Narol system than on a long-baseline system.

1.3.3 Time-Sync Errors. Time-sync errors are defined as the errors in measuring relative time of arrival not attributable to propagation irregularities of the pulse from the detonation point to the receivers. Time-sync errors consist of the human and instrumentation errors. The accuracy with which two pulses can be compared by envelope matching

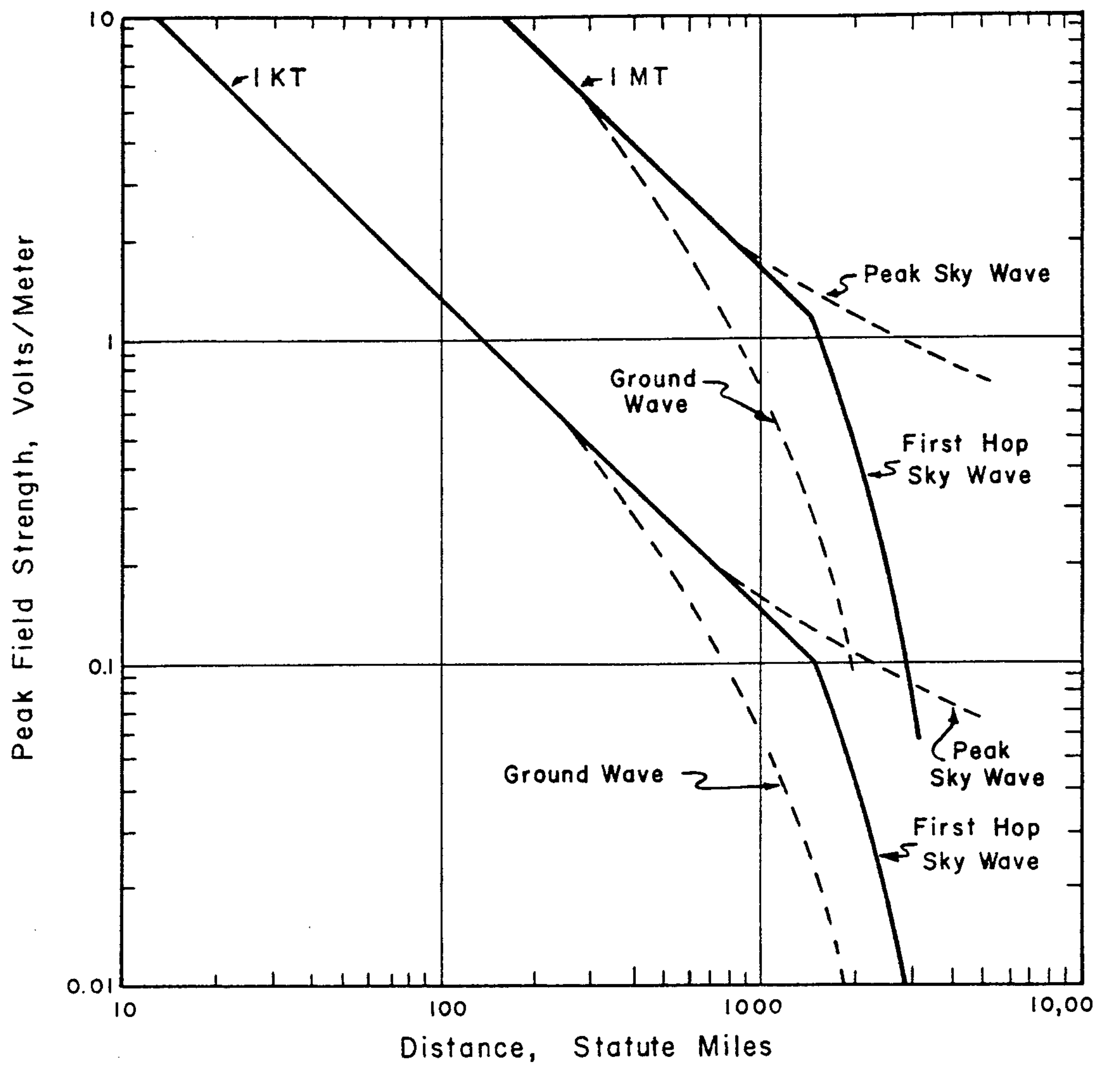


Figure 1.4 Field strength versus distance for 1-kt and 1-mt detonations. Curves are empirical and are based on correlation of field data with theoretical attenuation curves presented by Wait and Campbell in Reference 6.

for relative time-of-arrival analysis does not, in general, vary except with pulse length. If the recorded waveforms have their amplitudes equal and the envelopes are superimposed visually, and if the signal-to-noise ratio is good, the error in the time-difference measurement is usually about 1 percent of the pulse length for standard Loran. This accuracy can be realized in practice with Loran because the two signals to be compared pass through the same receiving networks and encounter exactly the same artificial delays and distor-



[redacted]

tions; the measured time difference is therefore not affected by the circuit parameters, except to the extent that the pulses are lengthened beyond their actual duration.

In the Narol system, where the two signals to be compared pass through different receiving networks, circuit parameters must be precisely identical or the network must be very carefully adjusted and calibrated to reduce the measurement errors. Thus, the maximum accuracy that could be expected in a Narol system should be less than that of Loran. Since the overall bomb-pulse length is usually from 30 to 80 microseconds at its

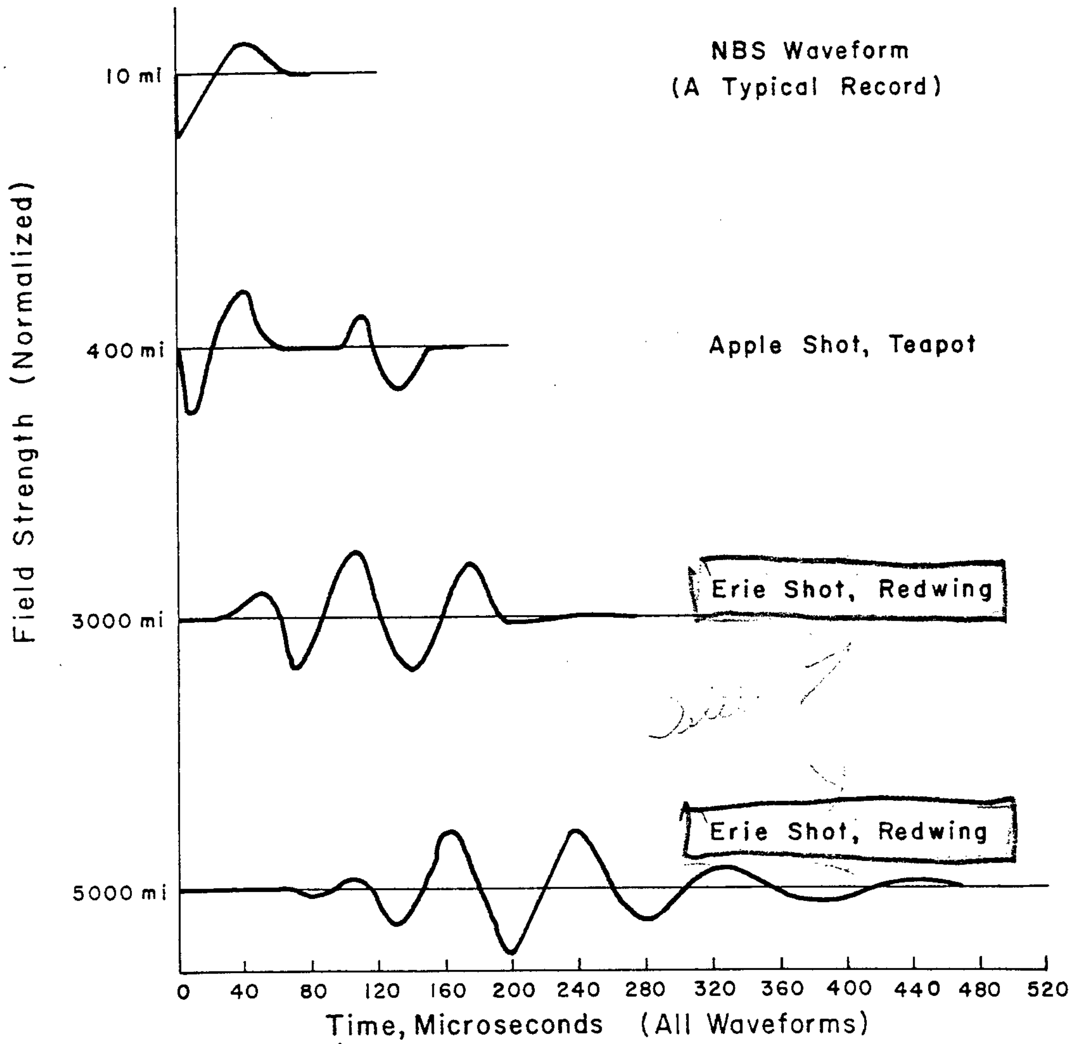


Figure 1.5 Waveforms resulting from a 15-kt weapon at various distances. Waveforms above show the distortion of a typical bomb pulse by its propagation medium as it moves away from the bomb.

source and about 500 microseconds at 5,000 miles from the source, the maximum Narol relative time-of-arrival resolution to be expected from an envelope-matching technique is 0.3 microsecond at the source and 5 microseconds at 5,000 miles. In practice, if the two receivers are about the same distance from the source, variances in the forms of the received signals caused by receiving and transmitting with two sets of equipment increase the errors by a factor of from two to ten.

To increase the precision of relative time-of-arrival measurements in the short-



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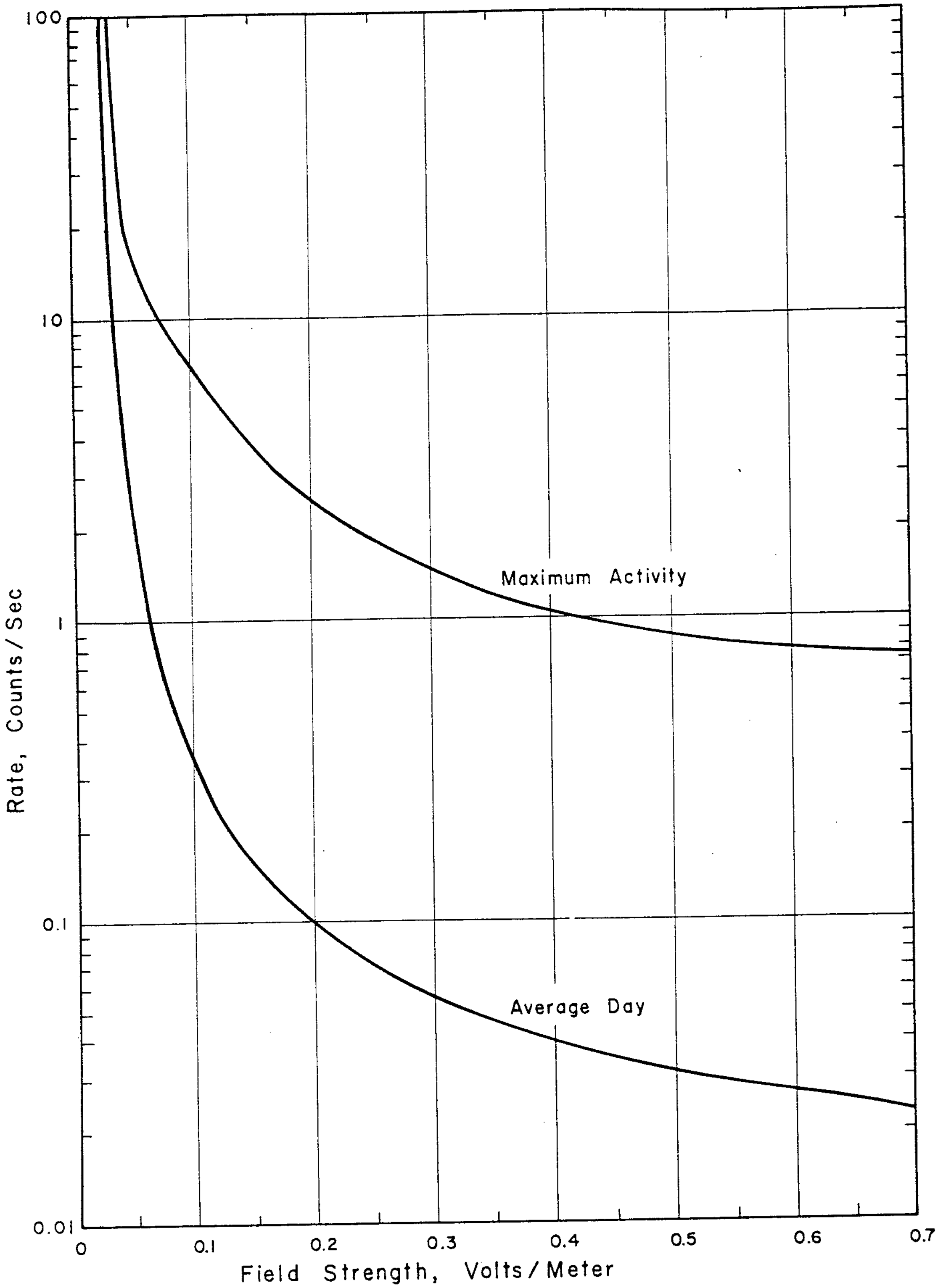


Figure 1.6 Rate of atmospheric transients versus field strength.



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baseline system, a cycle-matching technique is preferable to envelope matching. With this technique, the recorded signals from the two slave stations are matched by superimposing respective oscillations of the signals. Since the Loran error in the time-difference measurement by this technique is also about 1 percent of the length of the matched portions of the pulse, relative time-of-arrival resolution to an ultimate accuracy of about 0.2 microsecond is the best to be expected of a Narol system by matching half cycles of 20-microsecond duration. Difficulty can be experienced in determining with certainty the proper portions of the two recorded signals to match. However, with short-baseline systems, irregularities caused by mixing of the various sky-wave modes of propagation give character to the pulse, which in turn assists in the selection of the proper cycles to match.

Instrumentation errors in the short-baseline system are introduced by variable equipment delays and variable microwave propagation velocities from the slave stations to the

TABLE 1.1 LIGHTNING-TRANSIENT INTERFERENCE RATE

| Distance from bomb to receiving stations | Number of lightning transients with field strength equal to a 50-kt (air-burst) detonation |
|---|---|
| naut mi | |
| 300 | 1/min |
| 600 | 1/sec |
| 1,500 | 5 to 10/sec |
| 2,000 | 50 to 100/sec |

central master station. Since all predictable delays can be calibrated out of the system, the instrumentation errors are determined by measuring the unpredictable variations of the round-trip relative time of arrival of simulated bomb pulses generated at the master station. The instrumentation error of the short-baseline Narol system used in this test was ± 0.2 microsecond.

The time-sync error of the short-baseline Narol system, including analysis and instrumentation errors, was ± 0.4 microsecond; the baseline was about 500 microseconds (100 miles). Therefore, the angular resolution of the lines of position was ± 0.0008 radian from the true line of position.

1.3.4 Pulse Isolation. The greatest uncertainty in the development of a practical Narol IBDA system is the identification of the signals received at the receiver sites as being the bomb pulse. Figure 1.6 shows the rate of lightning-transient arrivals as a function of field strength with data taken in the southwestern United States. The arrival rates at times of maximum thunderstorm activity of lightning transients having field strengths equal to or greater than a 50-kt air burst at certain assumed ranges are listed in Table 1.1. Although these data may vary widely with location and weather conditions, they do indicate the formidable problem that exists in distinguishing a bomb pulse from lightning.

In standard Loran, the repetition frequency of the transmitted pulses is used for pulse identification. With a Narol system, which operates on a single pulse, it is possible to match a bomb pulse from one receiver with a lightning transient from the other unless some means is provided to distinguish between them. When a short-baseline system is used, there is enough character in the recorded bomb-pulse signals to permit a match with high reliability by the operators. However, where the probability of a significant number of lightning transients originating in the area of surveillance is great, some means should be provided in the Narol system to electronically discriminate against the lightning or to assist the operators in rapidly selecting the correct data for analysis.



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## Chapter 2

# PROCEDURE

### 2.1 OPERATIONS

The Narol geometry tested on this operation was a compromise between a 500-mile and an 800-mile system. Two nets at about 500 miles from the Nevada Test Site (NTS) were located at Albuquerque, New Mexico, and Vale, Oregon, and one at about 850 miles was located at Rapid City, South Dakota. Line-of-position angles approximating 90 degrees were obtained with the two 500-mile nets. Table 2.1 presents information concerning the field sites established, and Figure 2.1 illustrates the relative disposition of the nets.

In an operational system, three nets are desirable to detect errors in recording or analysis at one of the nets. The 850-mile net in the Rapid City area provided the third line of position and supplied additional data on the Narol system reliability as a function of range and yield.

Mobile units were engineered and tested in the Albuquerque area and then moved to the field sites selected. Logistically feasible field site locations were chosen to satisfy the Narol geometry and microwave-transmission requirements. The Narol geometry (see Figure 2.2) required two slave stations separated by about 100 miles, such that a line from the NTS to the net was perpendicular (± 30 degrees) to the line connecting the two slave sites. Maps of the U. S. Geological Survey (1 to 24,000 scale) covering the general area were analyzed in detail for technical and logistical feasibility before initial selection of the sites. The existence of the line-of-sight requirement for microwave transmission was determined by plotting profile charts of the terrain between likely sites. After selection of specific sites, project personnel inspected each for background radio noise, availability of power and telephone lines, and accessibility. The line of sight was checked visually to preclude errors from incorrect contours on the Survey maps.

### 2.2 INSTRUMENTATION

The system was engineered on the basis of recording and automatically processing film for all electromagnetic pulses arriving at the stations with a field strength of one half volt per meter or greater. At the Albuquerque and Vale nets, the bomb pulse was about one half volt per meter for 6-kt events, and at the Rapid City net, about one half volt per meter for 18-kt events. Because the equipment exceeded the design criteria, the system was successfully operated on all events from which the electromagnetic yield was equal to or greater than that for an unshielded 0.1-kt device.

2.2.1 Equipment. The Narol instrumentation consisted of bomb-pulse receiver systems, microwave-link systems, timing systems, time-of-arrival coincidence systems, inter-net area gating systems, data-display systems and automatic-processing cameras (see Figures 2.3 and 2.4).

The bomb-pulse receiver system included a 24-foot whip antenna, a laboratory-built cathode follower, a laboratory-built low-frequency filter with a bandpass from 8 to 70 kc, and a Tektronix preamplifier. The function of the bomb-pulse receiver system was to

pick up the bomb pulse to be fed to the microwave link at the slave stations, and to trigger circuits at the master station that alerted the data-display system to the arrival of pulses from the slave stations.

The microwave-link system included a Raytheon KTR-1,000 microwave transmitter, a receiver, and antennas. Its function was to transmit the bomb pulses from the slave stations to the master station for time-of-arrival analysis.

The timing system included a General Radio frequency standard, a WWV receiver, and a laboratory-built time-mark generator. Its function was to record WWV world time

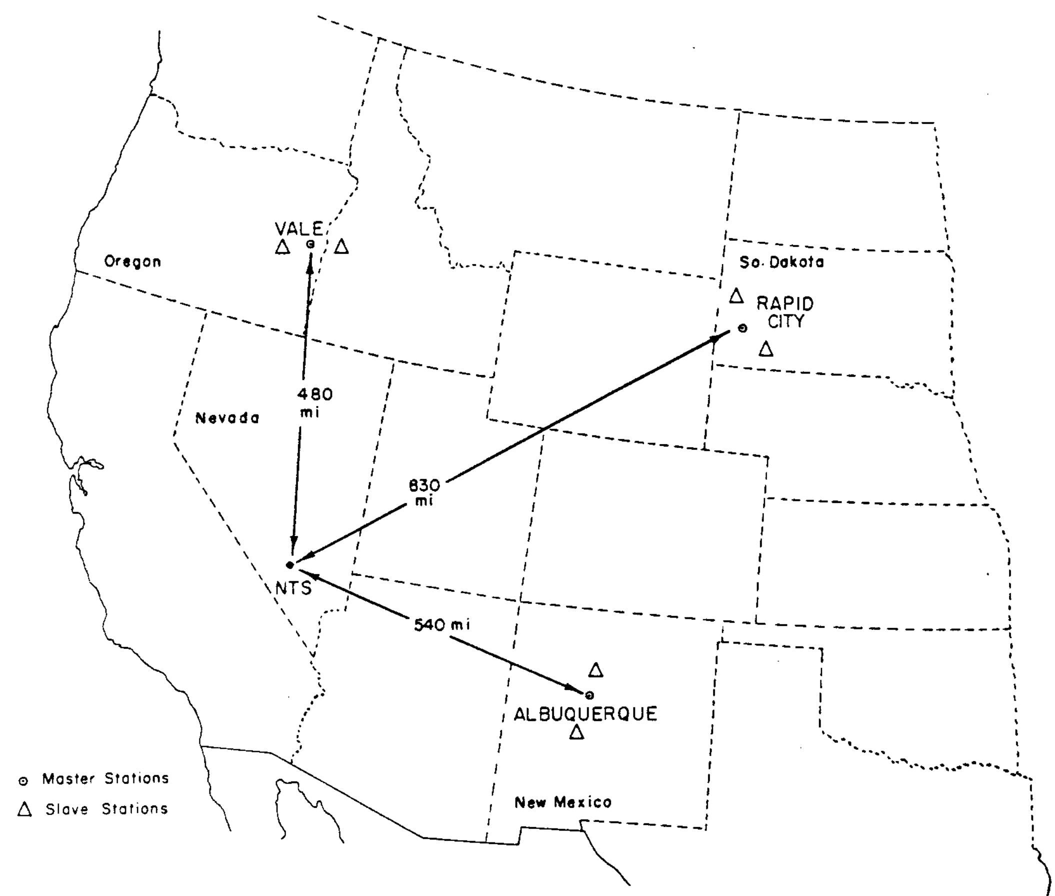


Figure 2.1 System geometric layout.

and generate accurate 10-microsecond time pips for presentation on the bomb-pulse display scopes for time-of-arrival measurement.

The time-of-arrival coincidence system was laboratory-built, and its function was to mark the film by means of neon lights when pulses arrived from the two slave stations with relative time-of-arrival differences that indicated they arrived from a hyperbolic sector of interest.

The area gating system was laboratory-built and served to alert the operators to analyze any pulse arriving at the three nets which originated in the target area.

The data-display system included a laboratory-built dual-tube oscilloscope to present the two slave-station pulses and the neon lamps that presented WWV world time, time-of-arrival coincidence, and area gating data for photography.

The automatic-processing camera was laboratory built and recorded the data on film,

processed the film, and projected the data for analysis. It was capable of handling film at the rate of 20 ft/min.

2.2.2 Area Gating System. As mentioned previously, the area gating system served to alert the operators to analyze any pulse arriving at the three nets which originated within a specific target area. The system was not incorporated into the equipment until Shot Smoky. Previous to this event, it had been hoped that a field-strength-discrimination method could be used to isolate the bomb pulse from lightning transients. When it was determined that the electromagnetic yield of some lightning strokes exceeded that of megaton-

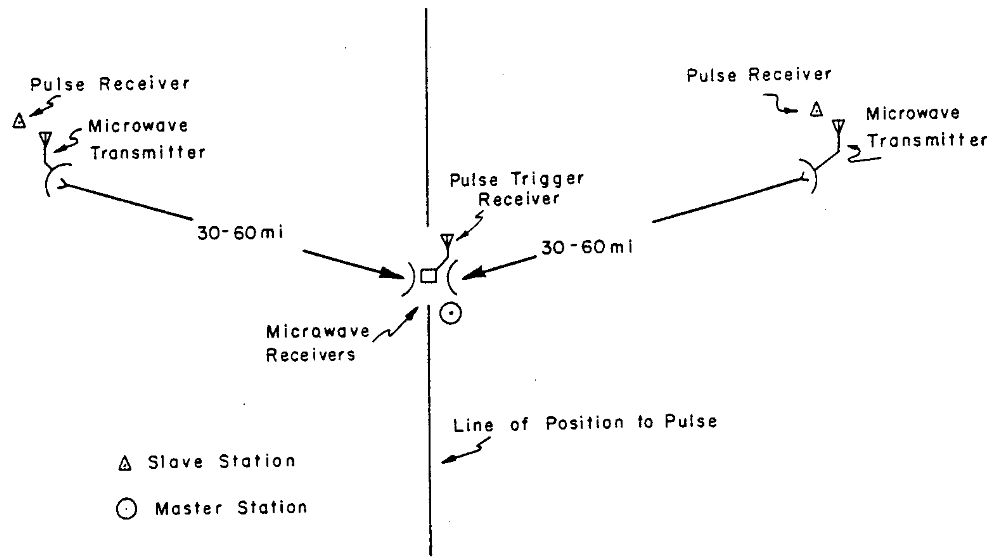


Figure 2.2 Narol net layout.

range detonations, this method was discarded for the area gating system, which assists in isolating the bomb pulse by limiting the amount of data that have to be analyzed.

The principal components of the system are illustrated in Figure 2.5, along with the sequence in which the signals that trigger the thyratron are generated. The system was located at the master station of each net and consisted of two trigger-generating circuits, a time-delay circuit, and a coincidence thyratron. The area gating system was contained in a standard 19-by-24-by-21-inch chassis and monitored one target at a time. Additional chassis can be installed to monitor more than one target at a time. The output of the thyratron was used to trigger a neon light on the data-display oscilloscope of the local net, and was transmitted over telephone lines to trigger an additional neon light at the other nets to indicate that a signal of interest has been received by the particular local net. All pulses arriving at each net were recorded on the display scopes of the net, but only those pulses marked by two or more neon lights were analyzed, since these originated within the target area of interest.

The functioning of the system was based on the fact that each LOP from a given net represents a given difference in time of arrival of a pulse at the slave stations of that net. Thus, by designing the triggering circuits and time-delay circuit to fire the thyratron when the difference in time of arrival falls between certain limits, the system will function only on pulses originating in a given hyperbolic sector.

Assuming that (1) a pulse originating along a given LOP from a specific target of in-



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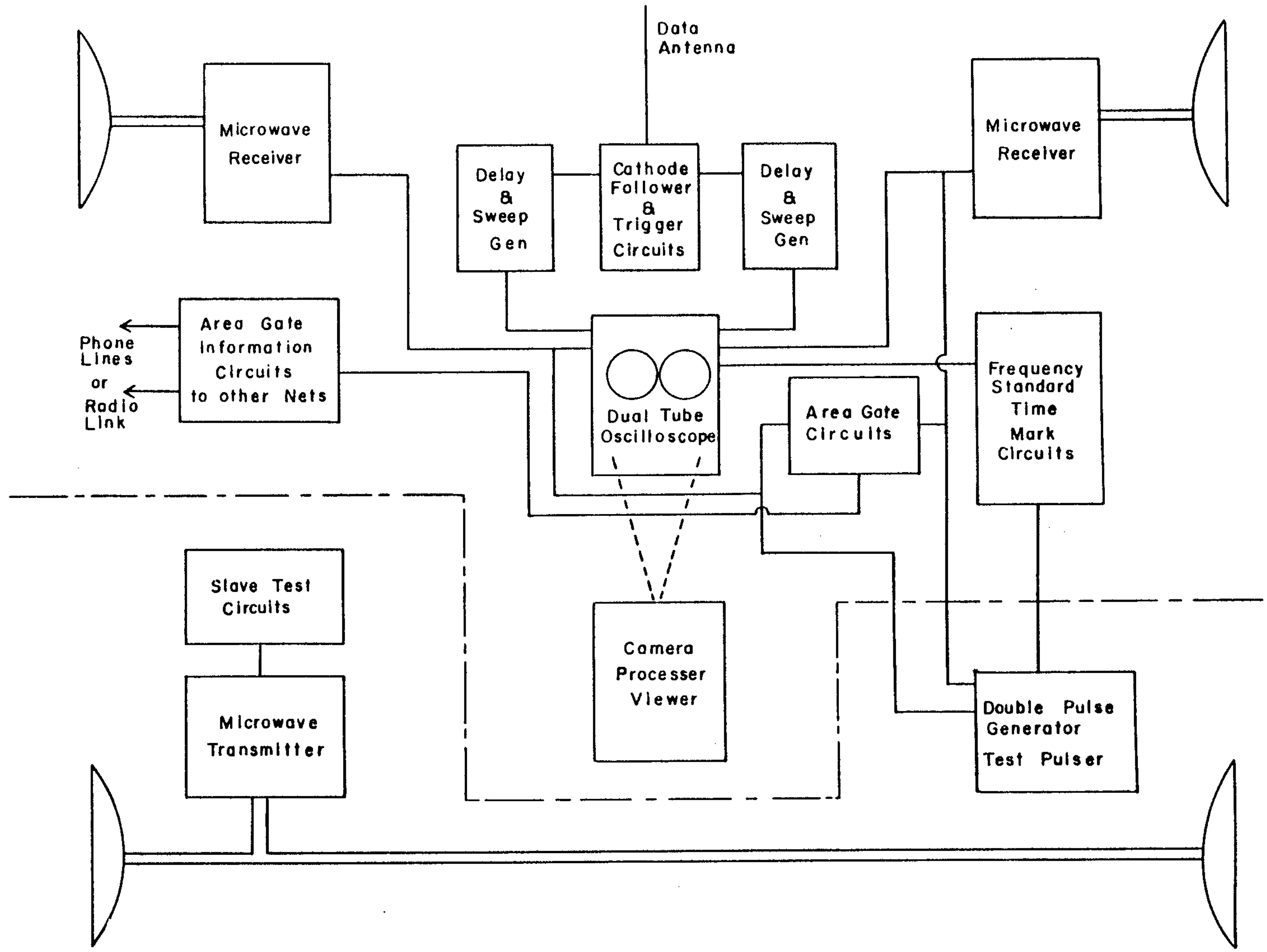


Figure 2.3 Master station block diagram. Equipment above broken line for data recording and analysis; equipment below line for test and calibration measurements.

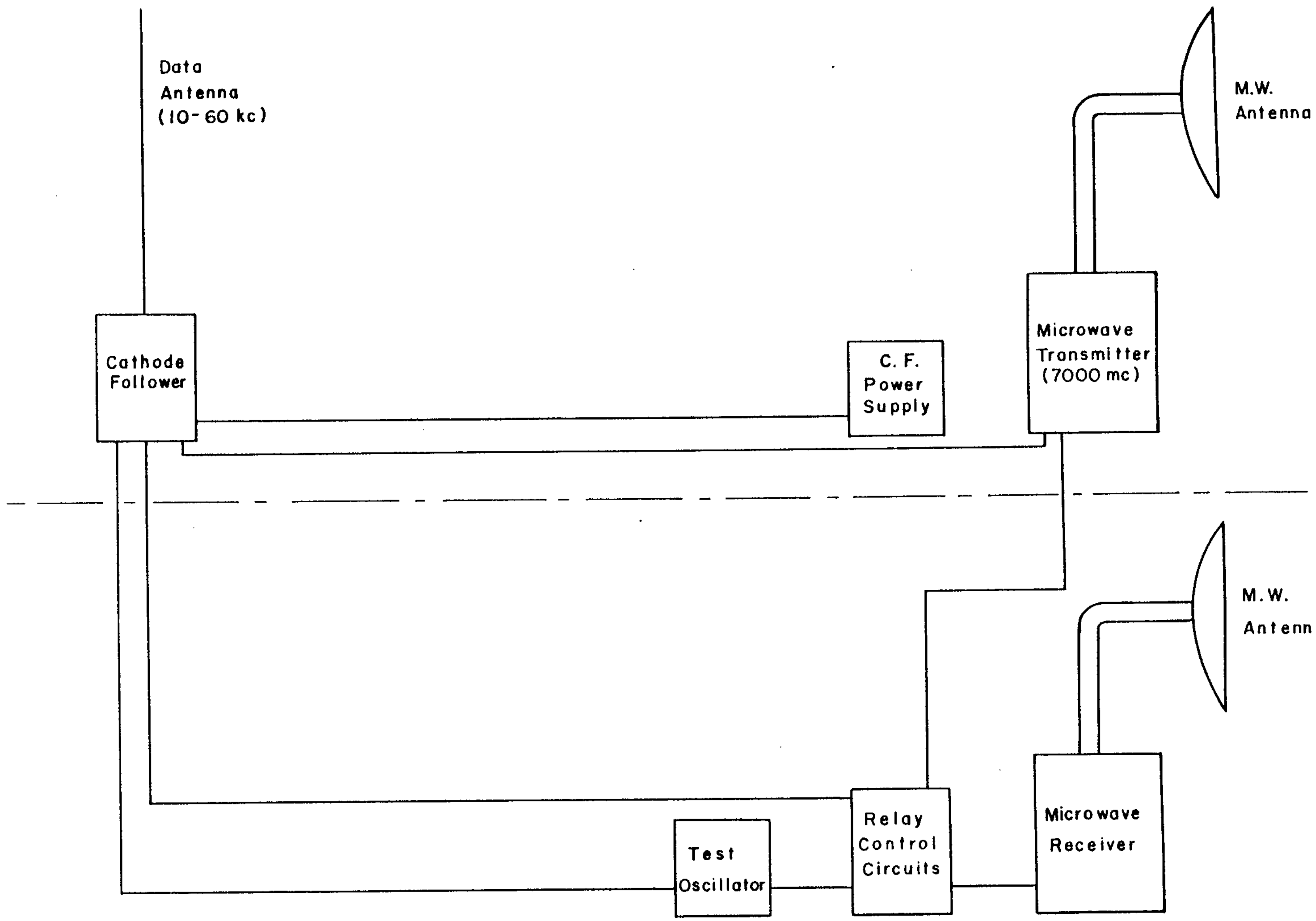


Figure 2.4 Slave station block diagram. Equipment above broken line used for pulse reception and relay to master station; equipment below broken line used for calibration and round trip delay measurements.

terest arrives at Slave A at a time $x$ microseconds before it reaches Slave B, (2) the signals transmitted from both slaves to the master station are used to actuate trigger circuits, and (3) the trigger output spike associated with Slave A is delayed $x$ microseconds so as to be impressed on the A grid of a coincidence thyratron at the same time the trigger spike associated with Slave B is impressed on the B grid—then the thyratron fires, indicating arrival of a pulse along the given LOP.

By making the output of the B trigger a 20-microsecond gate instead of a spike, and by further adjustment of the delay circuit, the thyratron will fire when pulses arrive that originated in a sector bounded by two LOP's having time differences of arrival of $(x+10)$

TABLE 2.1 PLUMBBOB NAROL SYSTEM

| Net | Distance to NTS naut mi | Station | Location | Latitude | Longitude |
|---|---|---|---|---|---|
| Albuquerque, New Mexico | 540 | Master | Kirtland A. F. Base | 34° 58′ 03.0″ N | 106° 38′ 18.6″ W |
| | | South Slave | Socorro Peak | 34° 04′ 22.4″ N | 106° 57′ 55.3″ W |
| | | North Slave | Pena Blanca | 35° 42′ 42.9″ N | 106° 23′ 16.8″ W |
| Vale, Oregon | 480 | Master | Vale, Oregon | 43° 58′ 50.0″ N | 117° 13′ 30.0″ W |
| | | West Slave | Westfall, Oregon | 44° 01′ 40.0″ N | 118° 01′ 21.0″ W |
| | | East Slave | Pearl, Idaho | 43° 52′ 10.0″ N | 116° 19′ 50.0″ W |
| Rapid City, South Dakota | 850 | Master | Rapid City, S. D. | 44° 06′ 47.0″ N | 103° 20′ 56.0″ W |
| | | N. W. Slave | Newell, S. D. | 44° 43′ 39.0″ N | 103° 19′ 27.0″ W |
| | | S. E. Slave | Scenic, S. D. | 43° 41′ 56.0″ N | 102° 34′ 54.0″ W |

microseconds and $(x-10)$ microseconds. Therefore, the area-gating acceptance angle of a given net is determined by the LOP's, $(x-10)$ and $(x+10)$ microseconds, and the intersection of the boundary LOP's from two or more nets establishes the area-gating acceptance area of the Narol system.

The area-gating acceptance angle for the Narol system used on Plumbbob was determined by a 20-microsecond gate. This established boundary LOP's that were approximately 20 miles apart in the vicinity of the NTS. The acceptance area at the NTS was thus approximated by a circle about each specific detonation point with a radius of 10 miles.

2.2.3 Equipment Operation and Calibration. Each master station was connected by microwave links to slave stations 30 to 60 miles on each side. The three nets were connected by telephone coincidence circuits for area-gating analysis and isolation of bomb pulses.

The bomb pulse was received at the two slave stations and retransmitted to the master station by standard TV microwave transmitters for analysis. At the master station, the direct bomb pulse was converted into a trigger and fed through variable delay lines to trigger the sweep generators of the dual tube scope. The trigger delays were set for coincidence of the bomb pulse as it was received over the microwave links from the two slave stations. Round-trip test pulses transmitted from the master station were used to calibrate waveform distortions through the two slave stations and variable equipment delays.

Times of arrival of the bomb pulse at the two slave stations were used to determine the LOP's. The slave-station and master-station equipment delay plus the microwave delay was considered to be the total bomb-pulse delay and had to be subtracted from the recorded time of arrival at the master station to ascertain relative times of arrival of the bomb pulse at the slave stations.

An additional microwave link was installed at the master station to measure the

round-trip time of a simulated bomb pulse. The microwave round-trip time was the transit time of a test-pulse signal from the master station to the slave station and return; one-half of the microwave round-trip time was the microwave delay. Total bomb-pulse

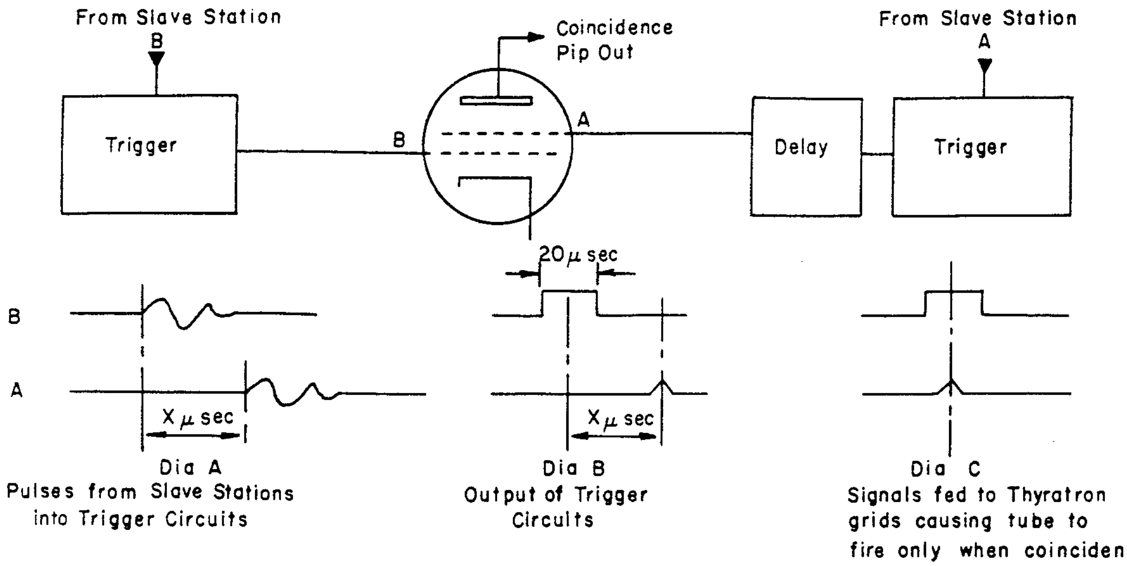


Figure 2.5 Pulse-time relationship.

delay included (1) one-way transit time through the slave-station receiver and filter delay, (2) slave-station microwave-transmitter delay, (3) propagation time from slave station to master station, and (4) delay through the master-station microwave receiver.

Time of arrival was determined as follows:

Microwave propagation time = $\frac{1}{2}$ [(measured round-trip time) − (sum of individual equipment delay times)]

Microwave link delay = (microwave propagation time) + (measured equipment delay of microwave transmitter and receiver)

Total bomb-pulse delay = (microwave-link bomb-pulse delay) + (bomb-pulse receiver and filter delay)

Slave-station time of arrival = (time of arrival at master station) − (total bomb-pulse delay)

Time-of-arrival difference = (time of arrival, slave-station A) − (time of arrival, slave-station B)

## 2.3 DESCRIPTION OF REQUIRED DATA

The bomb pulses were received at the slave stations and transmitted over microwave links to the master station for oscilloscope presentation. Automatic-processing cameras photographed the oscilloscope data for bomb-pulse time-of-arrival analysis. Auxiliary data in the form of neon lights displayed on the scopes were also recorded on the film.

These data included world time and inter-net coincidence marks for discrimination against lightning activity close to one net.

Figure 2.6 illustrates a typical film record. The analysis was accomplished as follows:

A bell alerted each net operator when the area-gating circuits indicated receipt of a

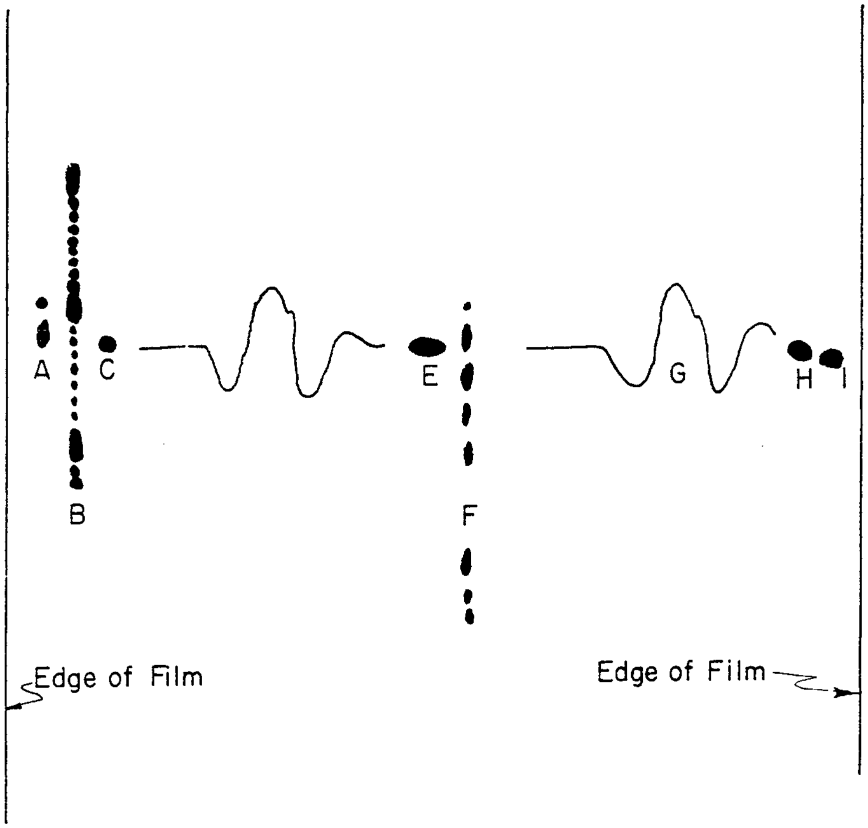


Figure 2.6 Typical data-film record. Legend: D, and G—scope traces of the pulse from the two slave stations used for time-of-arrival analysis; (the following are all neon lights used to record the data noted): A—recorded dashes at the rate of one per minute and dots at rate of one per second triggered from a WWV-synchronized secondary frequency standard; B—recorded dashes at rate of 0.1 per second and dots at the rate of 0.01 per second; C—recorded sweep trigger for world-time measurement in case of sweep displacement on oscilloscope; E—recorded arrival of pulses from local preset hyperbolic sector; F—recorded WWV time in code; H and I—recorded arrival of pulses from preset hyperbolic sectors at the other two nets as received over long-distance telephone lines.

pulse from the proper area. The net operators then measured the relative time of arrival of the pulse at the two slave stations. Each net transmitted by telephone the relative time of arrival in microseconds to the system control point at Kirtland AFB. The differences in time of arrival were plotted on Loran-type time-of-arrival maps to obtain LOP's for determination of the latitude and longitude of detonation. The wave forms D and G were later used for propagation and lightning-discrimination studies.

# Chapter 3
# RESULTS

Because of the shortage of engineering personnel, project participation did not commence at the start of the operation. The Albuquerque net was installed and operating by 28 May 1957, but was not fully calibrated until 10 June. The Vale net was operating on 28 May and calibrated by 24 June, and the Rapid City net on 18 June and calibrated by 19 July. Forty-three LOP's (from a possible 49) were obtained with the three nets during Plumbbob. Failure to obtain the other six possible LOP's was caused by power failures at the remote slave stations. Since the power required at the slave stations was low, this could be corrected by the use of 24-hour-capacity storage-battery packs kept charged by generators. None of the electronic equipment failed, and the unmanned slave stations worked properly throughout the operation. The project installation, maintenance, and operations were accomplished with a total of 18 personnel.

## 3.1 WORLD TIME OF DETONATION

Although world time of detonation is not involved in determining LOP's, it was used for after-the-fact verification that the bomb pulse was properly identified. Table 3.1 gives the detonation times measured from the film records and the times reported by the Test Director corrected for transmission. Excluding Shot John the average difference between the NTS times and the measured Narol times was about six milliseconds.

## 3.2 NAROL FIXES

The LOP's were measured at each net and plotted on a Narol fix map (see Figure 3.1). The intersection of the LOP's determined the Narol fix. Figures 3.2 and 3.3 are prints of the Albuquerque-net Shot Newton film and are representative of the data recorded at each net for all events.

Figure 3.2 is a print of the 300-microsecond sweep scope. This film was used for identification of the bomb pulse and rough measurement of relative time of arrival of the pulse at the master station. The sweeps on the two oscilloscope tubes were driven by a single waveform generator, and the two sweeps start at identical times. The relative time of arrival of the recorded signals is the time from the start of sweep number one to the pulse minus the time from the start of sweep number two to the pulse.

Figure 3.3 is a print of the 100-microsecond sweep scope. This film was used for accurate relative-time-of-arrival analysis. Each sweep was driven by separate waveform generators. The waveform generators were triggered by the bomb pulse arriving directly at the master station, with appropriate delays to center the signals from the two slave stations on the sweep. The analysis was made by overlaying the two slave station signals so that points at one half the maximum amplitude of each signal were matched. The time difference between the 10-microsecond pips on the two sweeps, plus or minus the number of tens of microseconds measured on the 300-microsecond sweep scope, gave the accurate relative time of arrival of the pulse at the master station.

The relative time of arrival at the slave stations is plotted on the Narol fix map in



[redacted]

Figure 3.1 for Shot Newton. The difference in propagation time from the two slave stations to the master station (total bomb-pulse instrument delay) was subtracted from the relative time of arrival of the slave signals at the master station before plotting the LOP on the map.

Table 3.2 gives the LOP errors for each net and the Narol fix errors for the Plumbbob

TABLE 3.1 WORLD TIME OF DETONATION

Differences between NTS and Narol times (except for Shot John) averaged approximately 6 msec.

| Shot | Date | NTS World Time | Narol World Time |
|---|---|---|---|
| | | MST | ± 0.01 MST |
| Boltzmann | 28 May 1957 | 0455:00.166 | 0455:00.155 |
| Franklin | 2 June | 0454:59.955 | 0454:59.950 |
| Lassen | 5 June | 0334:03. | Not Received |
| Wilson | 18 June | 0445:00.295 | 0445:00.29 |
| Priscilla | 24 June | 0630:00.133 | 0630:00.13 |
| Hood | 5 July | 0440:00.074 | 0440:00.065 |
| Diablo | 15 July | 0430:00.068 | Shielded |
| John | 19 July | 0700:04.611 ± 0.5 | 0700:04.642 |
| Kepler | 24 July | 0449:59.932 | Shielded |
| Owens | 25 July | 0629:59.697 | 0629:59.685 |
| Stokes | 7 August | 0525:00.182 | 0525:00.175 |
| Shasta | 18 August | 0459:59.994 | Shielded |
| Doppler | 23 August | 0530:00.105 | 0530:00.10 |
| Franklin′ | 30 August | 0539:59.865 | 0539:59.86 |
| Smoky | 31 August | 0529:59.995 | 0529:59.998 |
| Galileo | 2 September | 0540:00.038 | 0540:00.040 |
| Wheeler | 6 September | 0544:59.990 | 0544:59.995 |
| LaPlace | 8 September | 0559:59.798 | 0559:59.79 |
| Fizeau | 14 September | 0944:59.848 | 0944:59.850 |
| Newton | 16 September | 0549:59.868 | 0549:59.869 |
| Charleston | 28 September | 0559:59.953 | 0559:59.955 |
| Morgan | 7 October | 0600:[illegible].064<br>00 | 0600:00.070 |

TABLE 3.2 NAROL LOP'S AND FIXES (NAUTICAL MILES)

| Shot | LOP Error Albuquerque | LOP Error Vale | LOP Error Rapid City | 2-LOP Fix Error | 3-LOP Fix Error |
|---|---|---|---|---|---|
| Boltzmann | 1.0 N | * | † | — | — |
| Franklin | 2.3 N | * | † | — | — |
| Wilson | 0.35 N | 0 | * | 0.35 N | — |
| Priscilla | 0.4 N | 0.2 E | 0.1 S | — | 0.3 E |
| Hood | * | * | 0.2 S | — | — |
| John | 0.5 N | 0 | 0.1 S | — | 0.3 N |
| Owens | 1.1 S | 0 | 0.2 N | — | 0.7 S |
| Stokes | * | * | 0.3 N | — | — |
| Doppler | * | 0.3 W | 2.4 S | 2.85 S | — |
| Franklin′ | * | 0.2 E | 0.4 S | 0.4 S | — |
| Smoky | 0.7 S | 0.7 W | 0.4 SE | — | 1.0 SW |
| Galileo | 0.1 S | 1.8 E | 0.7 N | — | 1.0 NE |
| Wheeler | 0.6 S | 0.3 E | 0.4 S | — | 0.6 S |
| LaPlace | 0.6 S | 0.4 W | 0.9 S | — | 0.9 S |
| Fizeau | 0.5 N | 0.2 W | 0.4 N | — | 0.5 N |
| Newton | 0 | 0.5 W | 0.7 S | — | 0.4 S |
| Charleston | 0.1 S | 0.1 W | 0.8 N | — | 0.5 NW |
| Morgan | 0.2 S | 0.2 E | 1.0 SE | — | 0.7 SE |
| Average | 0.6 | 0.35 | 0.6 | 1.2 | 0.6 |

* Power failure at slave station.

† Station installation incomplete.

shots. The LOP error is the perpendicular distance from the LOP to the actual detonation point, and the 3-LOP fix error is the distance from the center of the triangle formed by the three LOP's to the actual detonation point. The directions indicated after the errors



[redacted]

in the Table are the directions from the detonation points to the LOP's or fixes. Narol fix maps for each of the Plumbbob events appear in Appendix A.

## 3.3 FIELD-STRENGTH CHARACTERISTICS

The peak field-strength measurements were based on standard 25-foot vertical whip antennas. The antenna effective heights were measured by a URM-6 field-strength meter at each net. Although the relative values at each station were accurate to within 20 percent, the signal strength was affected by the local environment, and absolute field strengths at each station could be in error by a factor of two. The results of the field-strength measurements are shown in Table 3.3.

TABLE 3.3 GROUND AND SKY WAVE FIELD STRENGTHS

All field strengths are in volts/meter. GW, ground wave; SW, sky wave.

| Event | Yield kt | Albuquerque, N. M. | | | | Vale, Oregon | | | | Rapid City, So. Dakota | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Socorro | | Pena Blanca | | Pearl | | Westfall | | Newell | | Scenic | |
| | | GW | SW | GW | SW | GW | SW | GW | SW | GW | SW | GW | SW |
| Boltzmann | 11.5 | * | * | 0.7 | 1.0 | † | † | ‡ | ‡ | § | § | § | § |
| Franklin | 0.138 | 0.15 | 0.18 | 0.17 | 0.18 | † | † | ‡ | ‡ | § | § | § | § |
| Wilson | 10.0 | 1.0 | 1.3 | 0.6 | 1.0 | † | † | † | † | 0.3 | 1.0 | ‡ | ‡ |
| Priscilla | 38.0 | 1.2 | 1.2 | 0.81 | 2.0 | 1.39 | 2.13 | 1.32 | 2.18 | 0.4 | 1.1 | 0.3 | 0.80 |
| Hood | 77 | 0.65 | 1.0 | ‡ | ‡ | 1.3 | † | ‡ | ‡ | 0.5 | 1.2 | 0.5 | 1.2 |
| John | 1.7 | 0.09 | 0.16 | 0.08 | 0.13 | 0.16 | 0.20 | 0.16 | 0.20 | 0.02 | 0.05 | 0.01 | 0.02 |
| Owens | 9.2 | † | † | 1.2 | 1.9 | † | † | 1.2 | † | 0.3 | 0.7 | 0.2 | 1.0 |
| Stokes | 18.5 | 1.0 | 1.3 | ‡ | ‡ | 1.15 | 1.72 | ‡ | ‡ | 0.4 | 1.0 | 0.3 | 0.8 |
| Doppler | 10.5 | ¶ | ¶ | ‡ | ‡ | 1.42 | † | † | † | 0.33 | † | 0.36 | 0.63 |
| Franklin' | 2.0 | 0.41 | 0.64 | ‡ | ‡ | 1.45 | 1.28 | 1.28 | 1.90 | 0.22 | 0.85 | 0.40 | 1.06 |
| Smoky | 45 | 1.42 | † | 1.22 | 2.54 | ¶ | ¶ | 1.59 | 2.44 | 0.48 | 1.59 | 0.57 | 1.67 |
| Galileo | 11 | 1.08 | † | 1.36 | † | 1.54 | 2.45 | 1.76 | 1.80 | 0.50 | † | 0.50 | † |
| Wheeler | 0.7 | 0.35 | 0.34 | 0.25 | 0.28 | 0.48 | 0.68 | 0.46 | 0.58 | 0.06 | 0.19 | 0.11 | 0.3 |
| LaPlace | 0.2 | 0.55 | 0.76 | 0.40 | 0.48 | 0.75 | 0.9 | 0.89 | 0.96 | 0.21 | 0.68 | 0.20 | 0.6 |
| Fizeau | 10 | 0.89 | 3.3 | 1.43 | 1.88 | 1.6 | 2.51 | 1.2 | 1.93 | 0.18 | † | 0.43 | † |
| Newton | 12 | 1.2 | 3.24 | 0.54 | 1.43 | 1.5 | 2.63 | 1.39 | 2.44 | 0.3 | 1.4 | 0.43 | 1.73 |
| Charleston | 11 | 1.51 | 3.19 | 1.2 | 2.74 | 1.55 | 3.01 | 1.45 | 2.07 | 0.59 | 1.91 | 0.53 | 1.01 |
| Morgan | 75 | 1.25 | 3.04 | 1.52 | 3.04 | 0.99 | 1.73 | 1.39 | 2.23 | 0.3 | 1.04 | ¶ | ¶ |

* Microwave distortion.
† Off scale.
‡ Power failure at slave station.
§ Station installation incomplete.
¶ Loss of calibration signal.

A secondary purpose of the Narol IBDA system is yield determination. Figure 3.4 is a plot of the yield versus the field strength of the bomb-pulse ground wave and the peak amplitude of the sky wave for each net. Figures 3.5 through 3.10 show the scatter of points from the curves of individual yield versus field strength in Figure 3.4 and indicate that detonation yield can be determined to within a factor of about ten by correlation with field strength.

## 3.4 WAVEFORM CHARACTERISTICS

The recorded waveforms from the various events were not identical. Figure 3.11 shows that different events detonated at the same test area under very-similar conditions with nearly equal yields have dissimilarities in waveform. Appendix B contains the waveforms of all the Plumbbob events for each net. A relationship exists between frequency

components in the ground-wave pulse and the yield, as shown in Figure 3.13, which plots the duration of the first half-cycle as a function of yield.

## 3.5 LIGHTNING PULSE CHARACTERISTICS

The first requirement of an operational Narol system is that it be able to isolate the bomb pulse for analysis. As discussed in Section 1.3.4, the bomb pulse is easily con-

TABLE 3.4 ELECTRONIC AREA GATING PERFORMANCE

| Shot | Smoky | Galileo | Wheeler | LaPlace | Fizeau | Newton | Charleston | Morgan |
|---|---|---|---|---|---|---|---|---|
| Area Gating Operation; number of nets recording coincidence on Albuquerque film | 3 | 2 | * | 2 | 3 | 3 | 3 | 2 |
| Albuquerque Local Hyperbolic Sector Mark | | | | | | | | |
| Spurious marks, rate per second | 0.05 | 0.55 | 0.1 | 0.01 | 0.01 | 0.01 | 0.01 | † |
| Occurrence of event mark | Yes | Yes | No | Yes | Yes | Yes | Yes | † |
| Vale Local Hyperbolic Sector Mark | | | | | | | | |
| Spurious marks, rate per second | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Occurrence of event mark | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Rapid City Local Hyperbolic Sector Mark | | | | | | | | |
| Spurious marks, rate per second | 0.01 | 0.01 | 0.8 | 0.08 | 0.01 | 0.01 | 0.01 | 0.01 |
| Occurrence of event mark | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Reception of Telephone Pulse at Albuquerque | | | | | | | | |
| Albuquerque pulse | Yes | Yes | * | Yes | Yes | Yes | Yes | — |
| Vale pulse | Yes | No | * | No | Yes | Yes | Yes | Yes |
| Rapid City pulse | Yes | Yes | * | Yes | Yes | Yes | Yes | Yes |

* Telephone receiving circuits not operating.
† Site deactivation.

fused with lightning transients. The Plumbbob Narol system was used to determine fixes on a large number of lightning transients. The recorded wave forms were analyzed for lightning-pulse characteristics as a function of range. Figure 3.12 illustrates the Narol-fix map used to determine the position of individual lightning strokes.

Figures 3.14 and 3.15 show the distribution of ground-wave and sky-wave lightning-pulse field strengths as a function of distance. Superimposed on the Figures are the curves of ground-wave and sky-wave field strength versus distance for 1-megaton and 1-kiloton bomb pulses (see Figure 1.4). Figures 3.14 and 3.15 indicate that the electromagnetic yields of lightning transients vary over a range equivalent to that existing between a 1-megaton and a 1-kiloton yield and cannot be used as a means of discrimination.

Figure 3.16 shows the waveform of four lightning transients recorded on one film from the Rapid City net with ground-wave field strengths and ranges that are about the same as the bomb pulses of Figure 3.11. Comparison of the two Figures indicates that the lightning pulses were similar at their source, and that the variations between the

Text continued on Page 41.

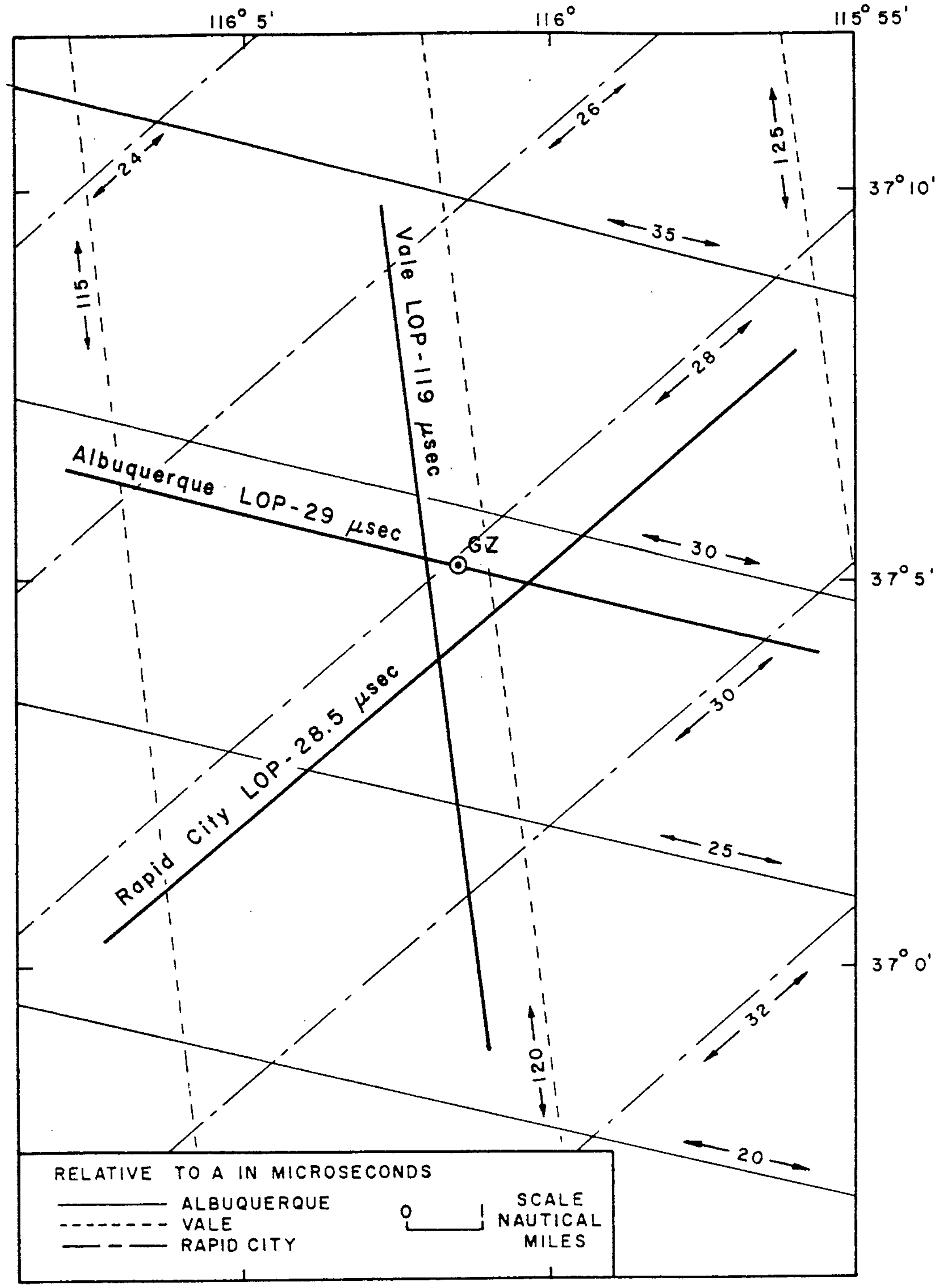


Figure 3.1 Representative Narol fix map, Shot Newton.



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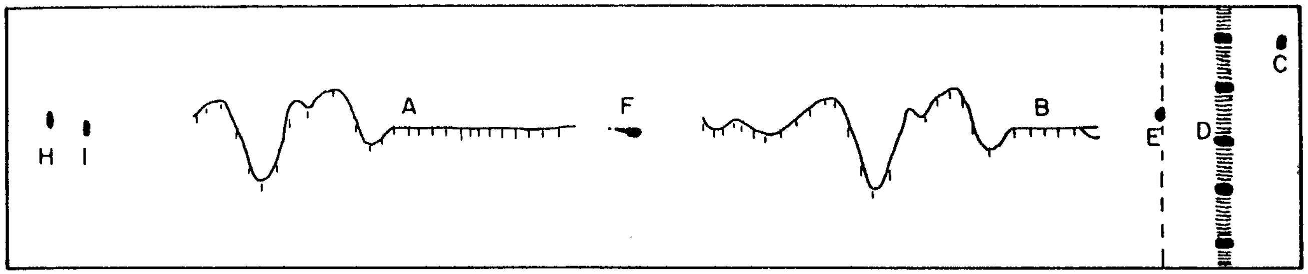


Figure 3.2 Albuquerque Shot Newton film (300 microseconds sweep).

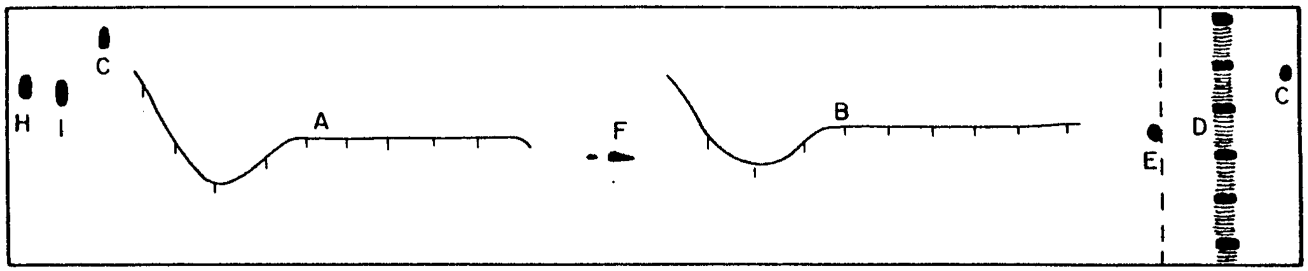


Figure 3.3 Albuquerque Shot Newton film (100 microseconds sweep). Legend for Figures 3.2 and 3.3: A, B—are the scope traces of the pulse from the two slave stations which are used for manual time-of-arrival analysis; pips superimposed on sweeps are 10-microsecond markers; C—recorded dashes at the rate of one per minute and dots at rate of one per second triggered from a WWV synchronized secondary frequency standard; D—recorded dashes at rate of 0.1 per second and dots at the rate of 0.01 per second; E—recorded sweep trigger for world time measurement in the presence of sweep displacement on oscilloscope; F—recorded arrival of pulses from local preset hyperbolic sector; H, I—recorded arrival of pulses from preset hyperbolic sectors at the other two nets as received over long-distance telephone lines.

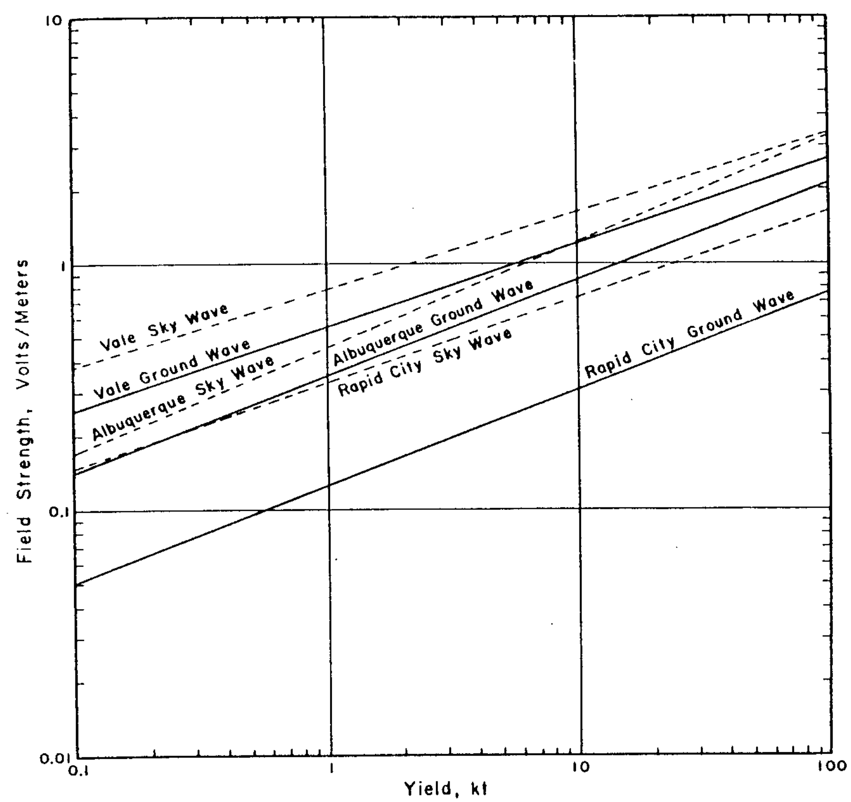


Figure 3.4 Sky- and ground-wave field strengths versus yield. Approximate distances to Nevada Test Site: Albuquerque, 540 miles; Vale, 480 miles; and Rapid City, 830 miles.

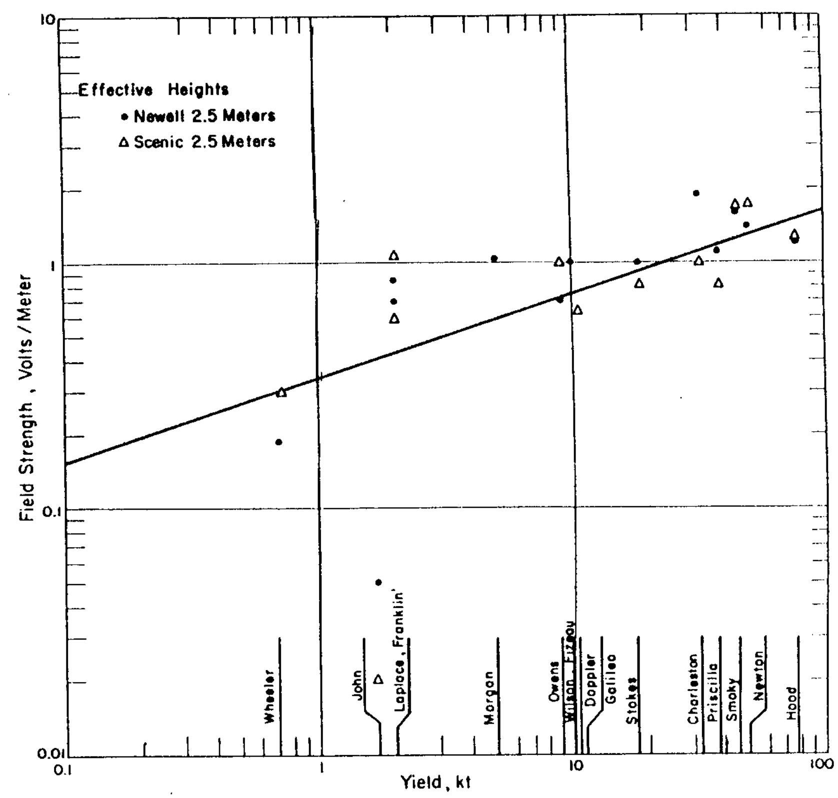


Figure 3.5 Rapid City net sky wave field strength versus yield.



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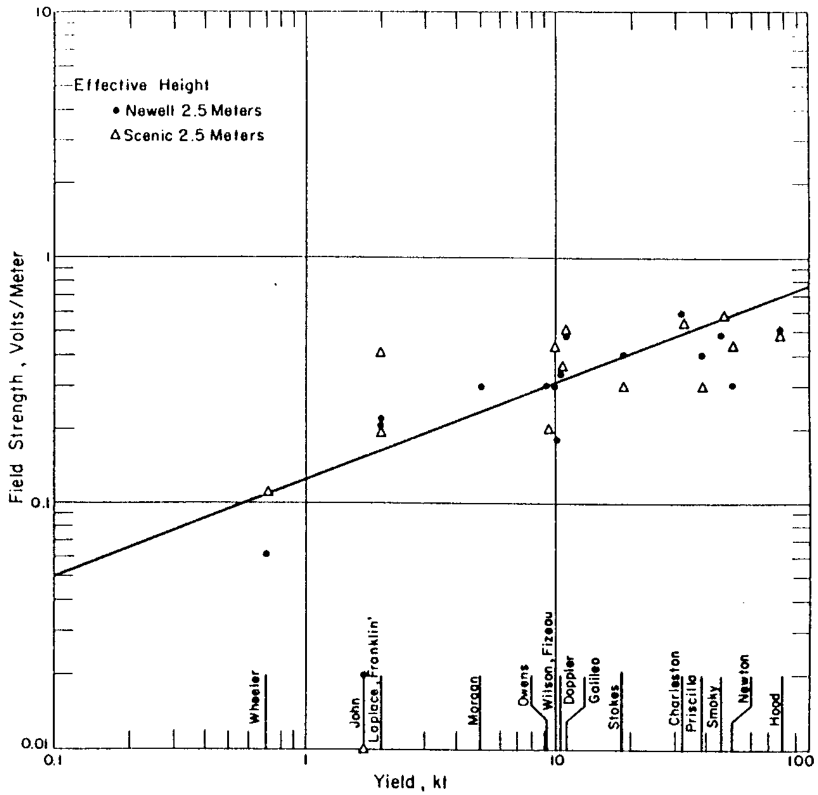


Figure 3.6 Rapid City net ground wave field strength versus yield.

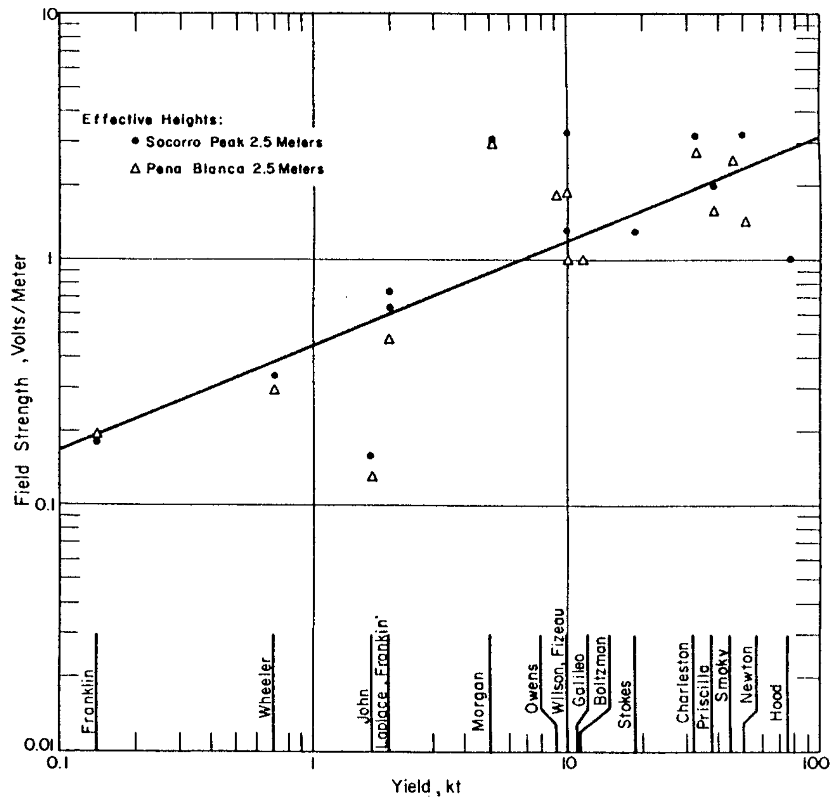


Figure 3.7 Albuquerque sky wave field strength versus yield.

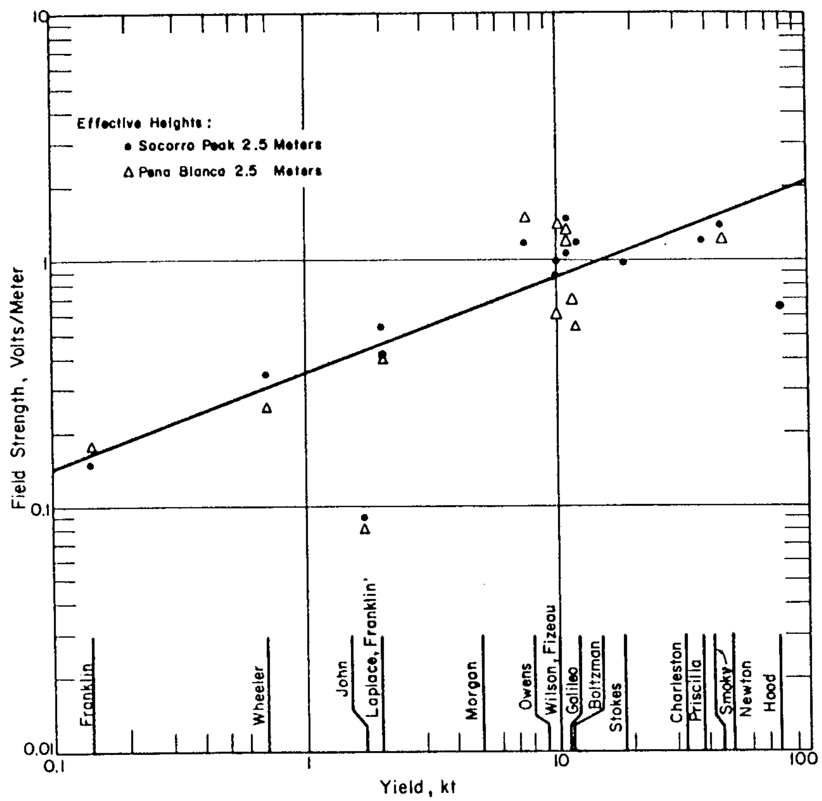


Figure 3.8 Albuquerque net ground wave field strength versus yield.

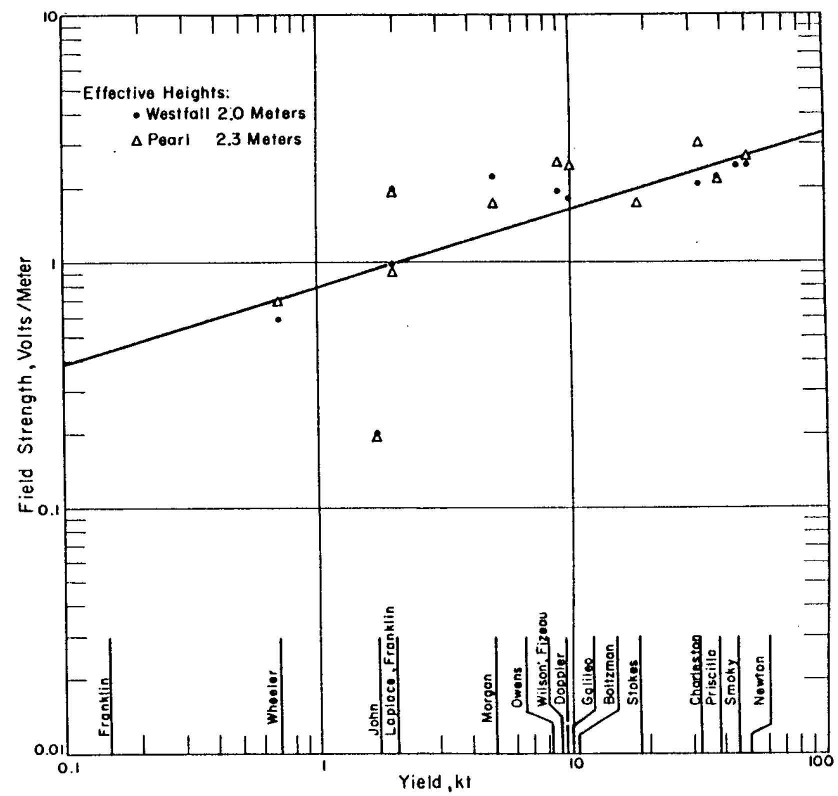


Figure 3.9 Vale net sky wave field strength versus yield.



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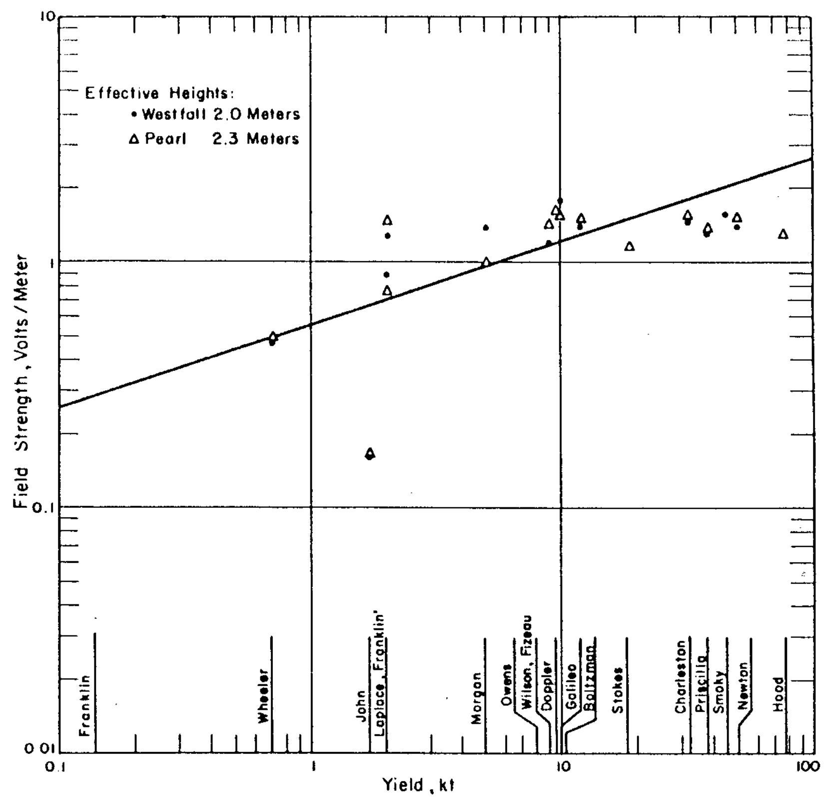


Figure 3.10 Vale net ground wave tield strength versus yield.

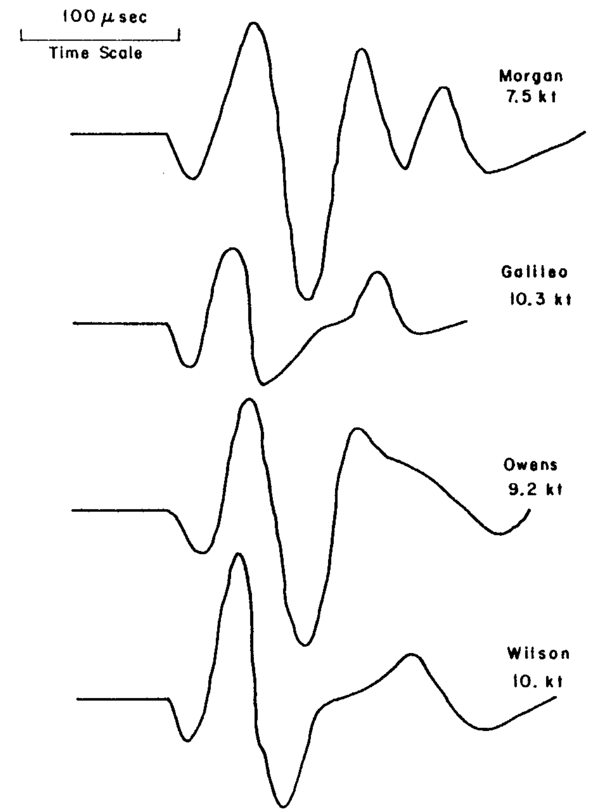


Figure 3.11 Bomb waveforms, Rapid City; distance from Nevada Test Site, 830 miles; approximate yield, 10 kt. For ease of comparison, the waveform amplitudes have been normalized so that the amplitude of the first half-cycle equals 1 centimeter.

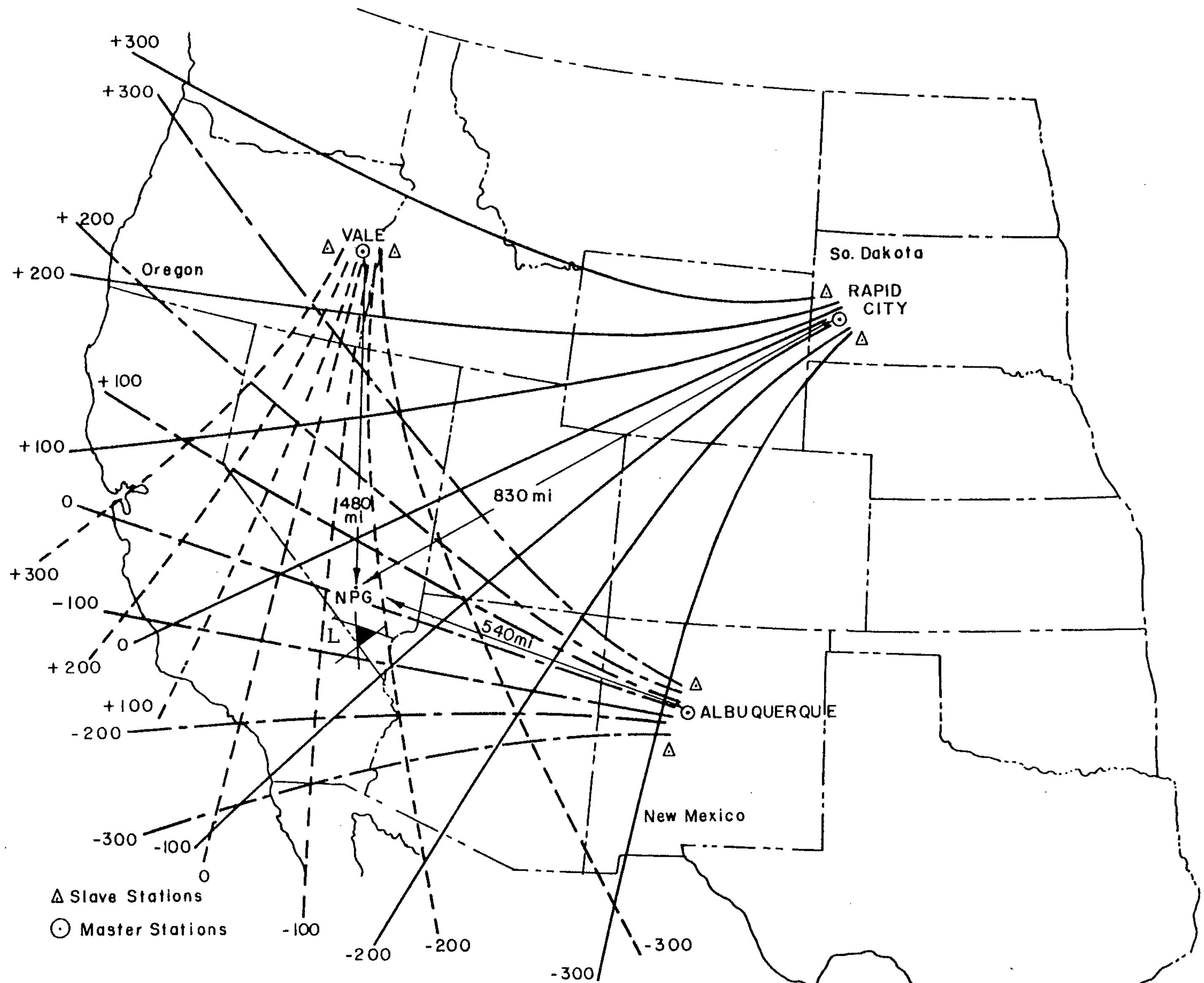


Figure 3.12 Illustration of Narol map used to locate source of lightning. L: representative lightning fix; world time: 10 July 1957, 1516:28.00; fix coordinates: latitude, 35° 48′ N, longitude, 115° 12′ W; size of fix triangle: 40 by 34 by 35 miles.

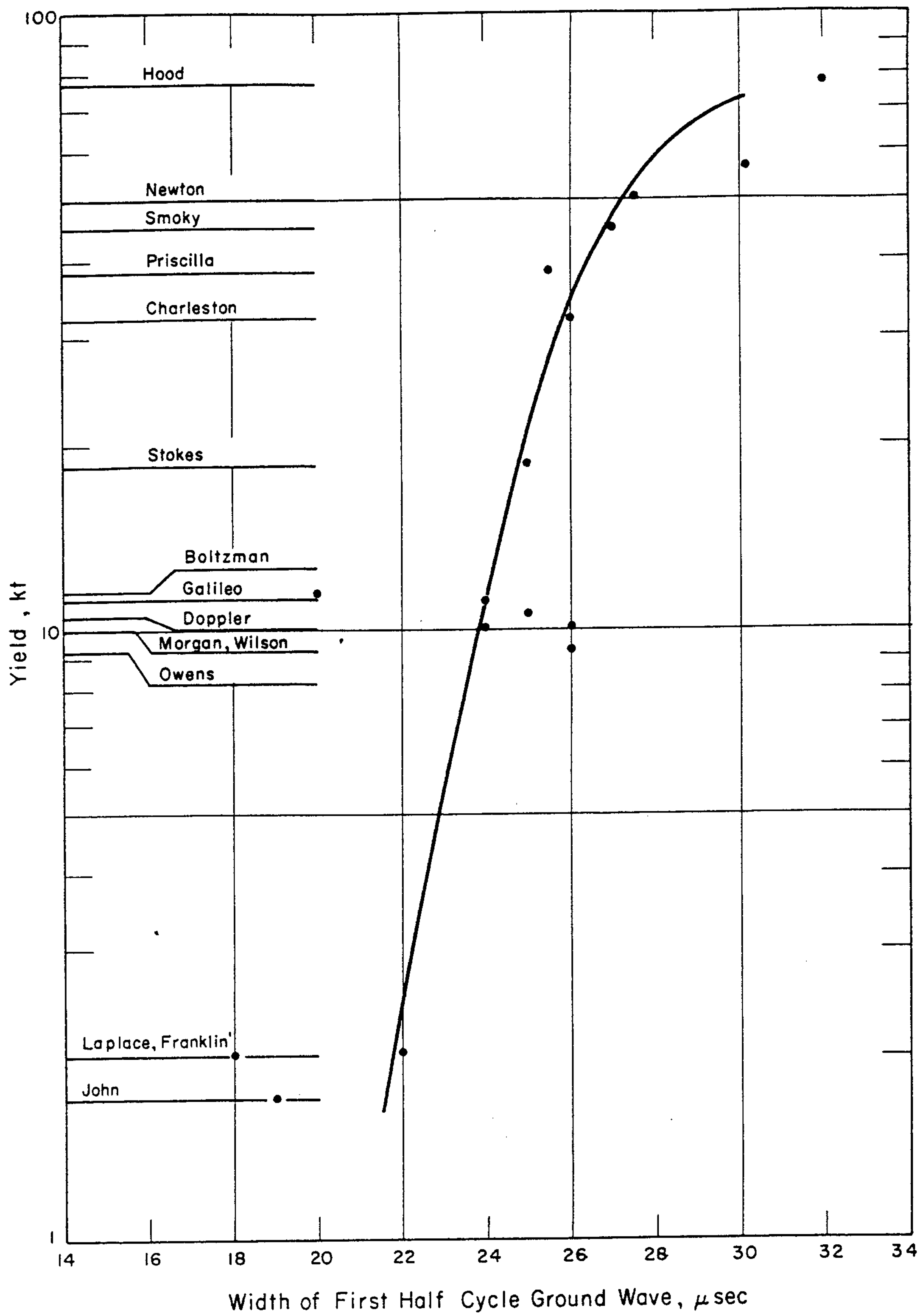


Figure 3.13 Duration of first half cycle of ground wave versus yield.



[redacted]

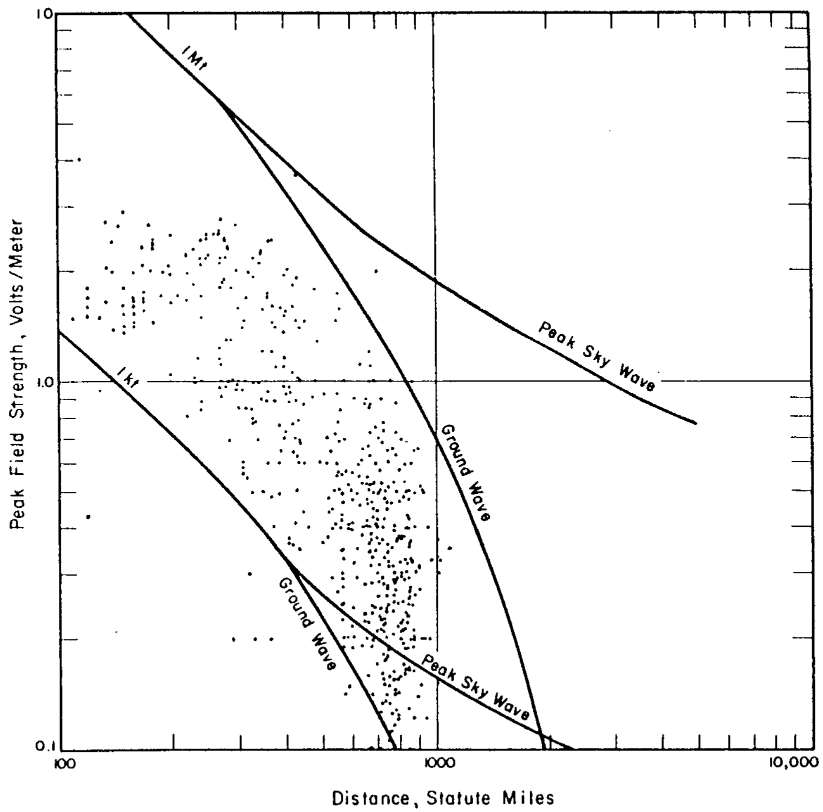


Figure 3.14 Lightning ground-wave amplitude versus distance; 215 three-station fixes.

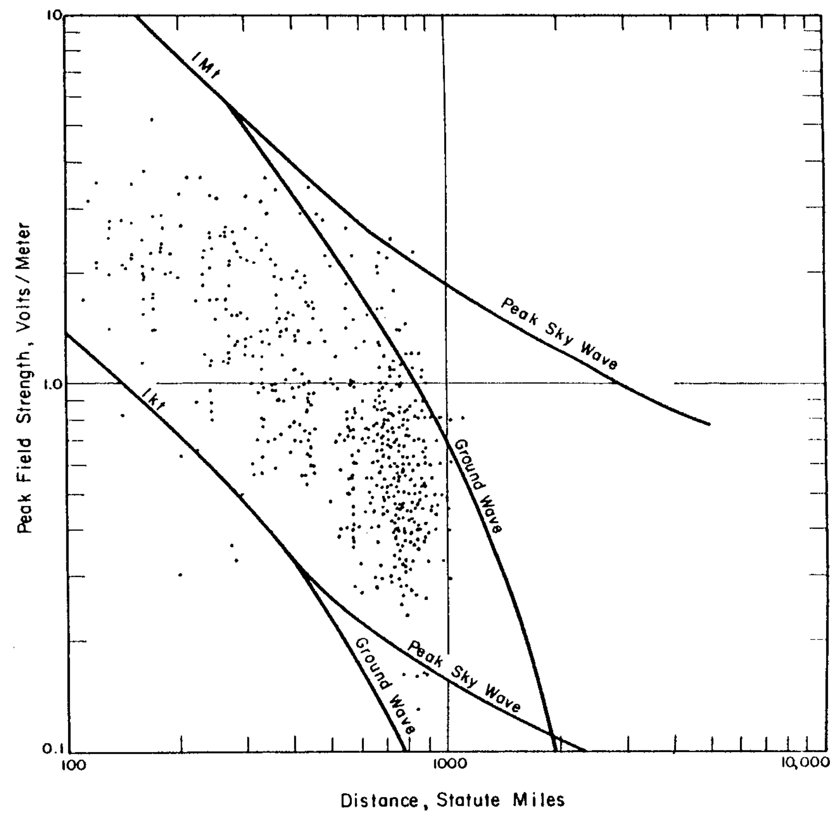


Figure 3.15 Lightning sky-wave amplitude versus distance; 215 three-station fixes.



[redacted]

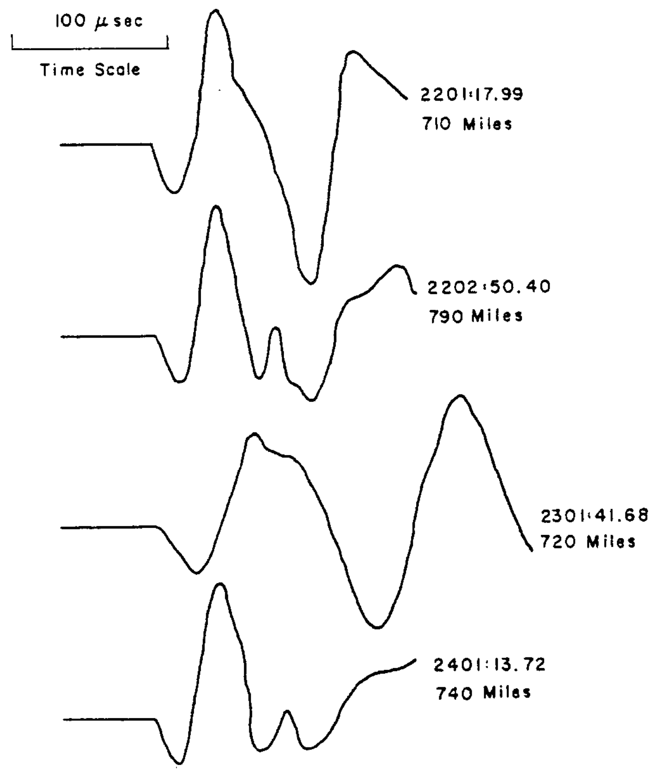


Figure 3.16 Lightning waveforms, Rapid City, 9 August 1957. Distances measured from Rapid City; times in GMT. Amplitudes approximately equal to 10-kt bomb pulse normalized; first negative pulse equals 1 centimeter.

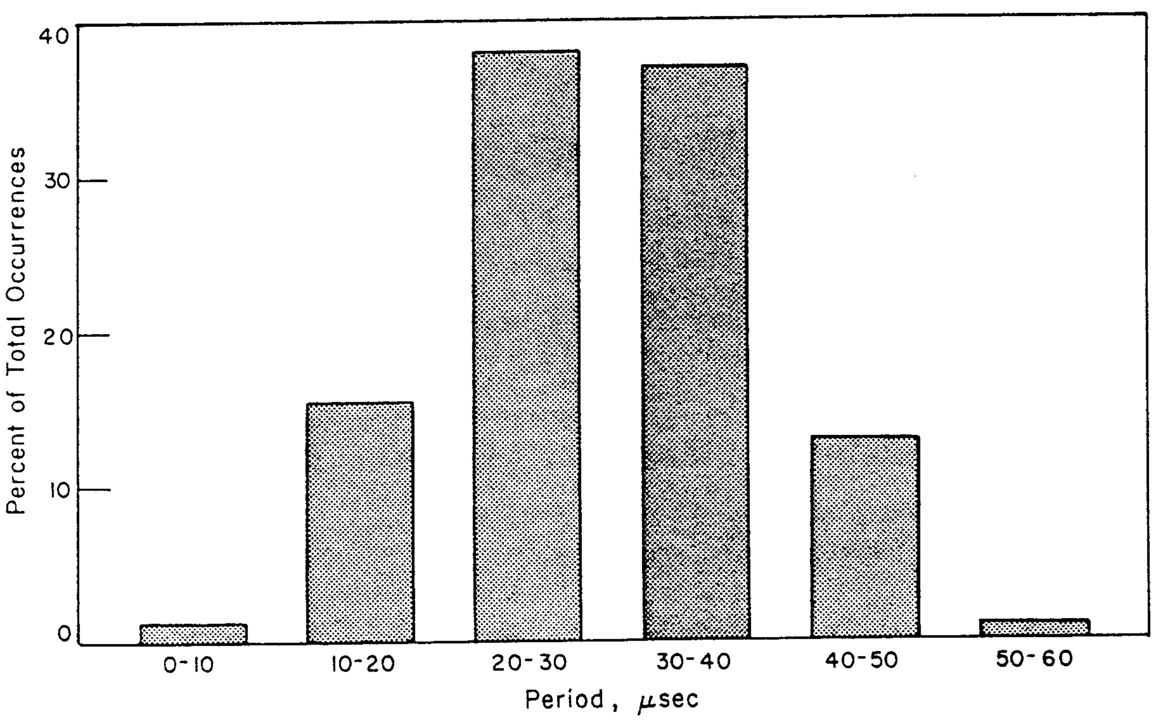


Figure 3.17 Distribution of first half cycle periods. Six days lightning data; total analyzed time: 13 minutes.



[redacted]

bomb- and lightning-pulse wave structures were caused primarily by intermixing of the sky-wave components and not by the ground wave. At ranges greater than 1,500 miles, the ground-wave portion of the pulse would have been completely attenuated, and the pulse structure would have been determined entirely by the mixing of the sky-wave modes. From Figure 3.17, the first ground-wave half-cycle of the recorded lightning pulses varied considerably and thus provided no basis for discrimination from bomb pulses.

All these data indicate that there is no consistent pattern peculiar to the wave forms, field strengths, or pulse durations of the lightning pulses that would distinguish them from bomb pulses.

### 3.6 AREA-GATING DISCRIMINATION

Due to the impossibility of pulse-characteristic discrimination, the area-gating system described in Section 2.2.2 was installed and operated, starting with Shot Smoky. Although the area-gating equipment was built in the field and installed late in the operation, double-net coincidences were recorded on the Albuquerque film for seven of seven possible events, and triple-net coincidences were recorded on four of six possible events. Table 3.4 gives the breakdown of the area-gating performance during Operation Plumbbob. This data indicates that the area gating system correctly marked the proper pulse for analysis on each event with a very-low false-alarm rate.

# Chapter 4

# CONCLUSIONS and RECOMMENDATIONS

## 4.1 BOMB-PULSE ISOLATION

The ideal method of bomb-pulse identification would be by electronic means dependent on the waveform, source field strength, or pulse duration. This would require no prior knowledge of time or position of the detonation. However, the Plumbbob lightning studies indicate that there is little chance of finding any positive, distinguishing characteristics of the bomb pulse for either human or electronic identification.

In the absence of identification by the nature of the received pulse, the position or time of detonation can be used as an aid to bomb-pulse identification. Both of these methods require advance knowledge of the plans for use of the nuclear weapons. Since the rate of lightning-transient arrivals is high, identification by time alone would require knowledge of world time of detonation to within milliseconds. With prior knowledge of specific targets, the approximate position of the detonation can be used to assist in bomb-pulse isolation by means of the area gating system. The reliability of area-gating identification depends on the degree of probability that any pulse arriving from the target area would be from a nuclear detonation. The area-gating reliability increases when strike-time uncertainties are small.

## 4.2 OPERATIONAL SYSTEM

The preferred system for SAC, TAC, and ADC would be capable of sustained monitoring of large areas without access to war plans for bomb-pulse identification. At the present time it seems that this objective is not possible. Therefore, there is no possibility of an operational system to satisfy the needs of ADC, where the position and time of enemy strikes in the United States would not be known. With the incorporation of area gating, the Narol system is capable of monitoring pre-selected targets in enemy territory and transmitting to the interested commands within fifteen minutes the information that an electromagnetic pulse originated at a particular point in the vicinity of one or more of these targets. Generally the chance of this electromagnetic pulse being the result of a lightning stroke appears to be remote; however, repeated lightning strokes from the target area combined with meteorological forecasts should give a high degree of reliability in differentiating between lightning transients and the bomb pulse. Approximately five minutes are required to set up the area gating for any specific target area. Although the SAC war plans are highly classified and could not be kept at operational Narol sites, it seems that the strike plans could be transmitted to the sites about five minutes before the earliest expected bomb release to enable area-gating adjustment for the selected targets. The system would be particularly useful for guided missiles where the time of detonation and position of the target is known at missile-release time.

# REFERENCES

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2. Kemper, J. A.; "Measurement of Electromagnetic Effects During Operation Castle"; NBS Report 30106; National Bureau of Standards, Washington, D. C.

3. Jean, A. G., and Taylor, W. L.; NBS Report 30118; National Bureau of Standards, Washington, D. C.

4. Final Engineering Report Cytac, Teapot Data Project; Contract AF19(604)-1429; Sperry Gyroscope Company, Great Neck, L. I., New York.

5. Wait, J. R., and Campbell, L. L.; "Transmission Curves for Groundwave Propagation at Low Radio Frequencies"; Report No. R-1; Radio Physics Laboratory, Defense Research Telecommunications Establishment (Canada), April 1953.

6. Pierce, J. A., McKenzie, A. A., and Woodward, R. H.; Loran, Radiation Laboratory Series, Volume 4, Chapter 3; McGraw-Hill Book Company, New York, 1948.

7. Houghten, R. A., and others; "Electromagnetic Detection Measurements"; Operation Teapot; AFCRC Report (in press); Air Force Cambridge Research Center, Cambridge, Massachusetts.

8. Houghten, R. A., and Humphrey, L. C.; "Short-Baseline Narol Measurements"; Project 6.1a, Operation Redwing, ITR–1336, May-July 1956; Air Force Cambridge Research Center, Cambridge, Massachusetts; Secret Restricted Data.

# APPENDIX A NAROL FIX MAPS

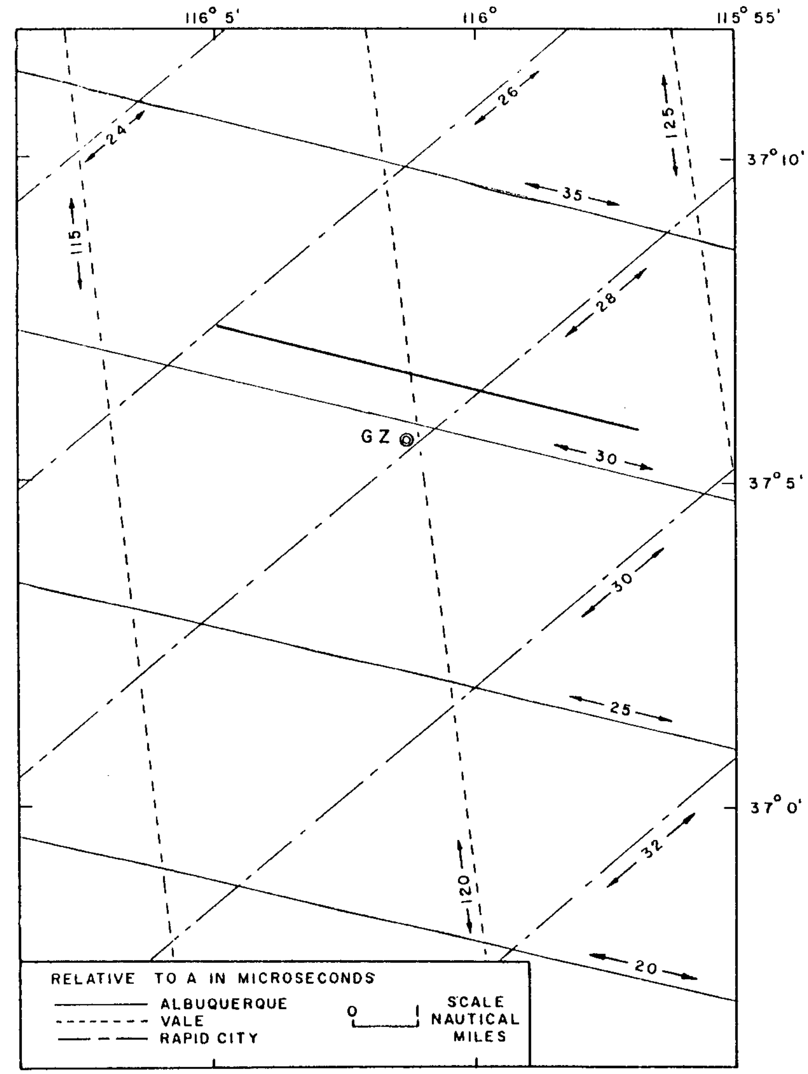


Figure A.1 Shot Boltzmann.

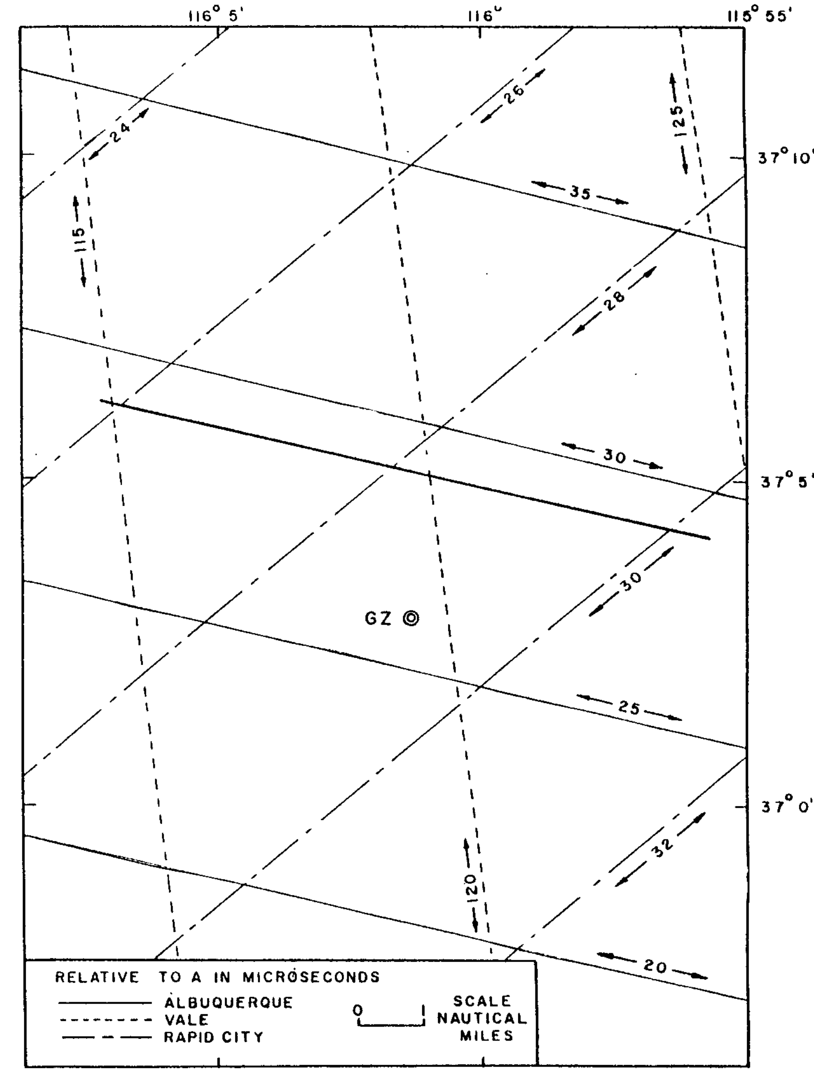


Figure A.2 Shot Franklin.



[redacted]

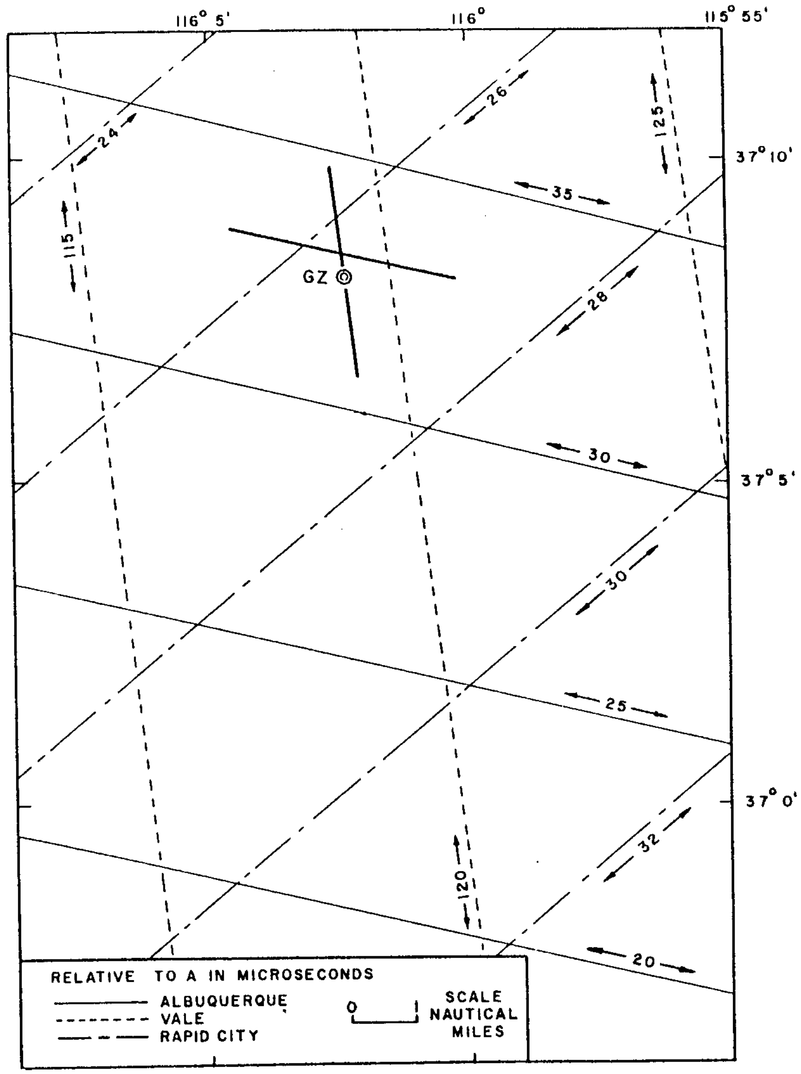


Figure A.3 Shot Wilson.

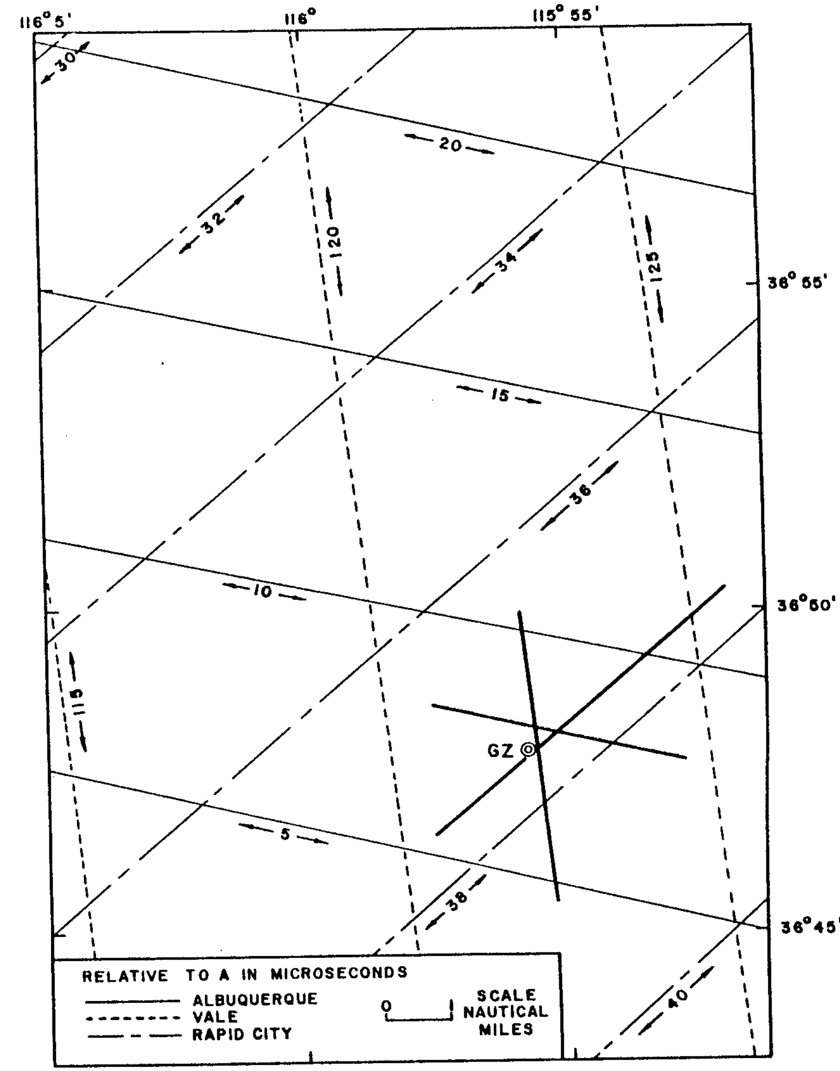


Figure A.4 Shot Priscilla.



[redacted]

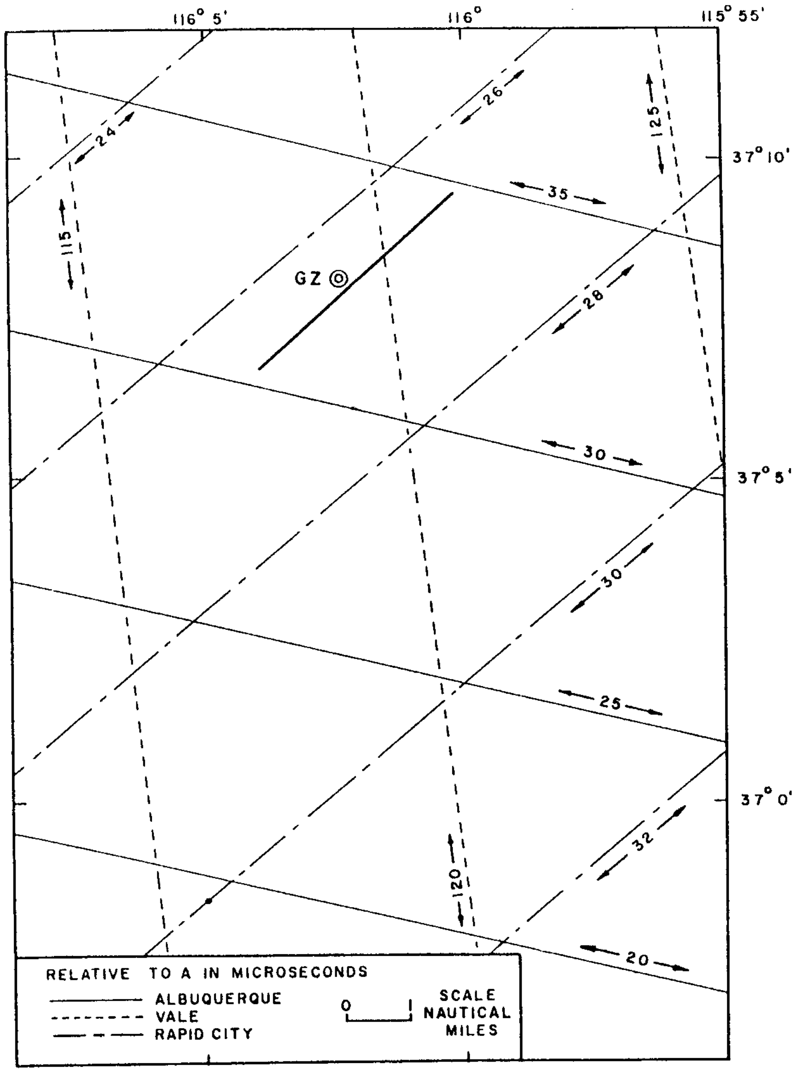


Figure A.5 Shot Hood.

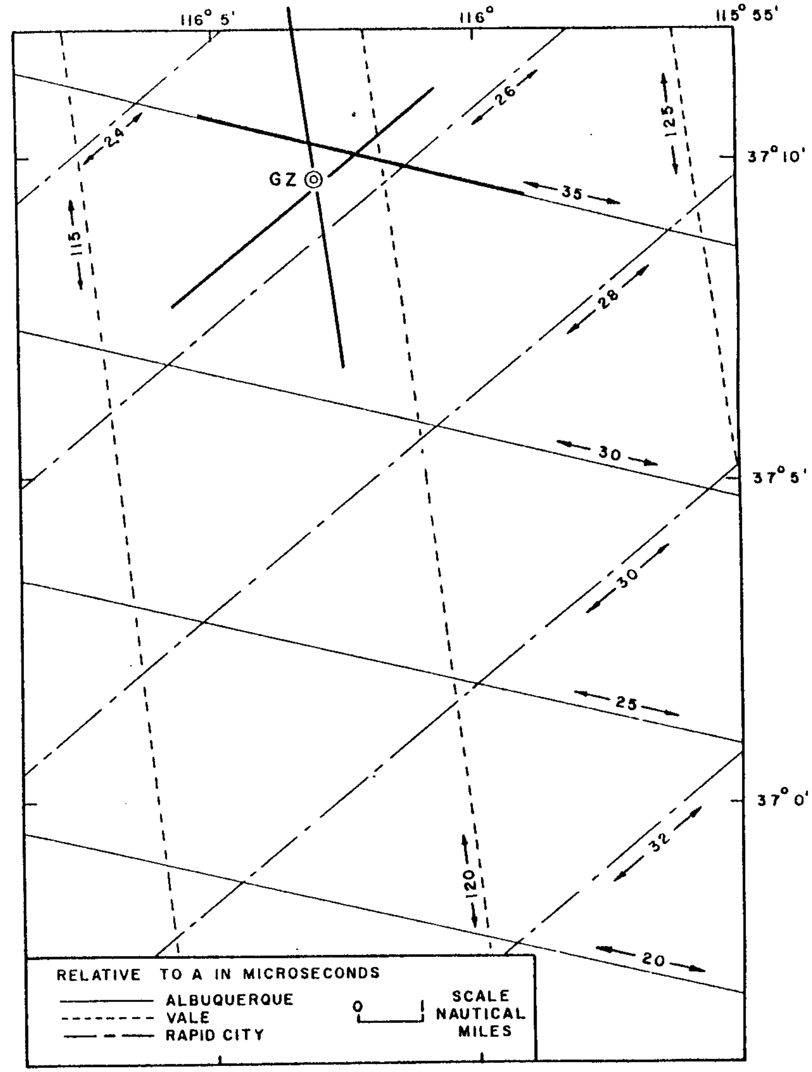


Figure A.6 Shot John.



[redacted]

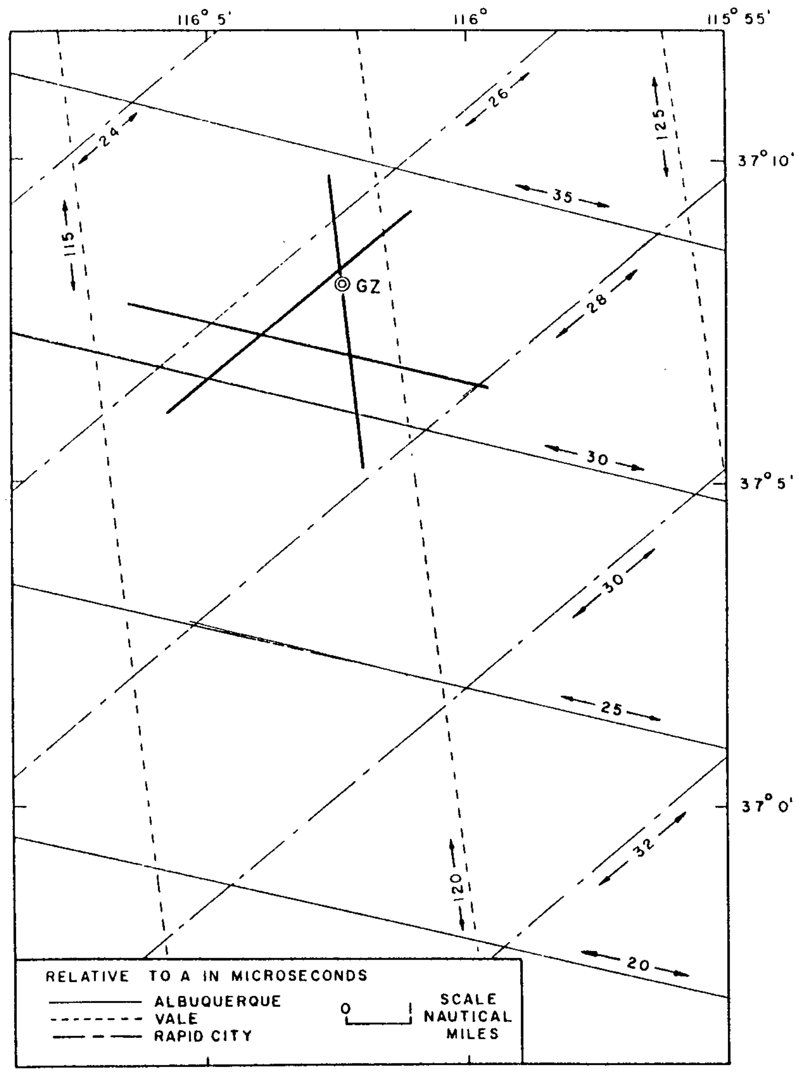


Figure A.7 Shot Owens.

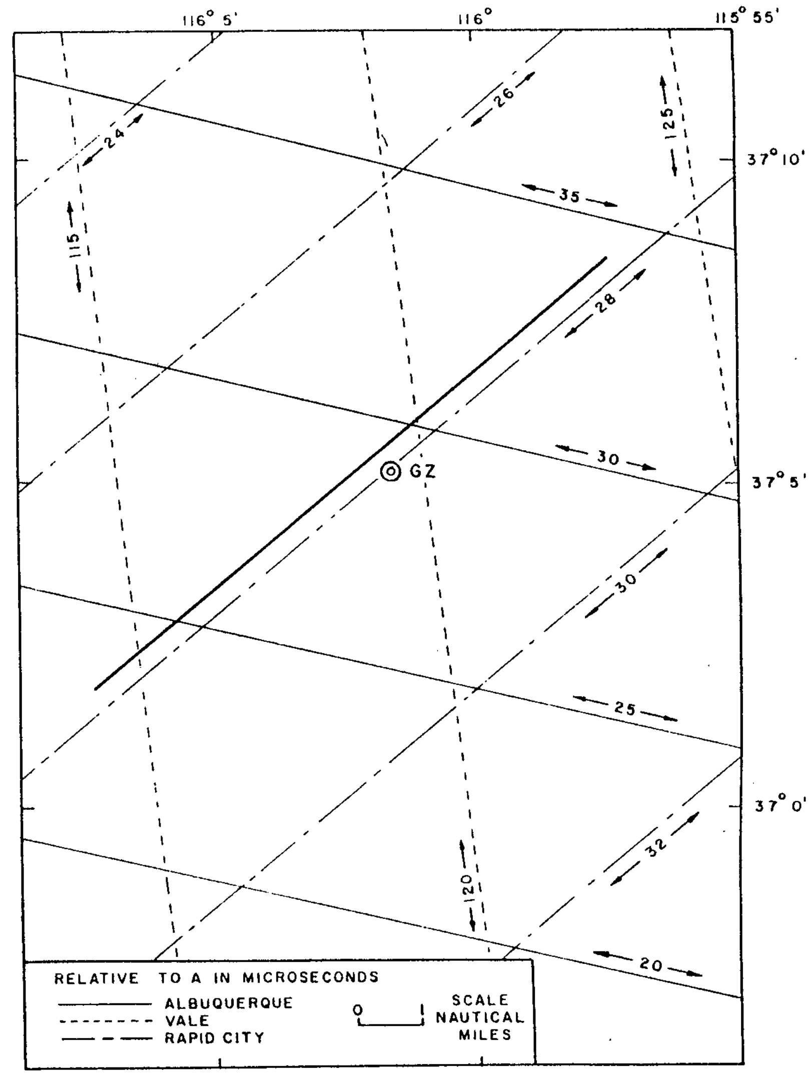


Figure A.8 Shot Stokes.



[redacted]

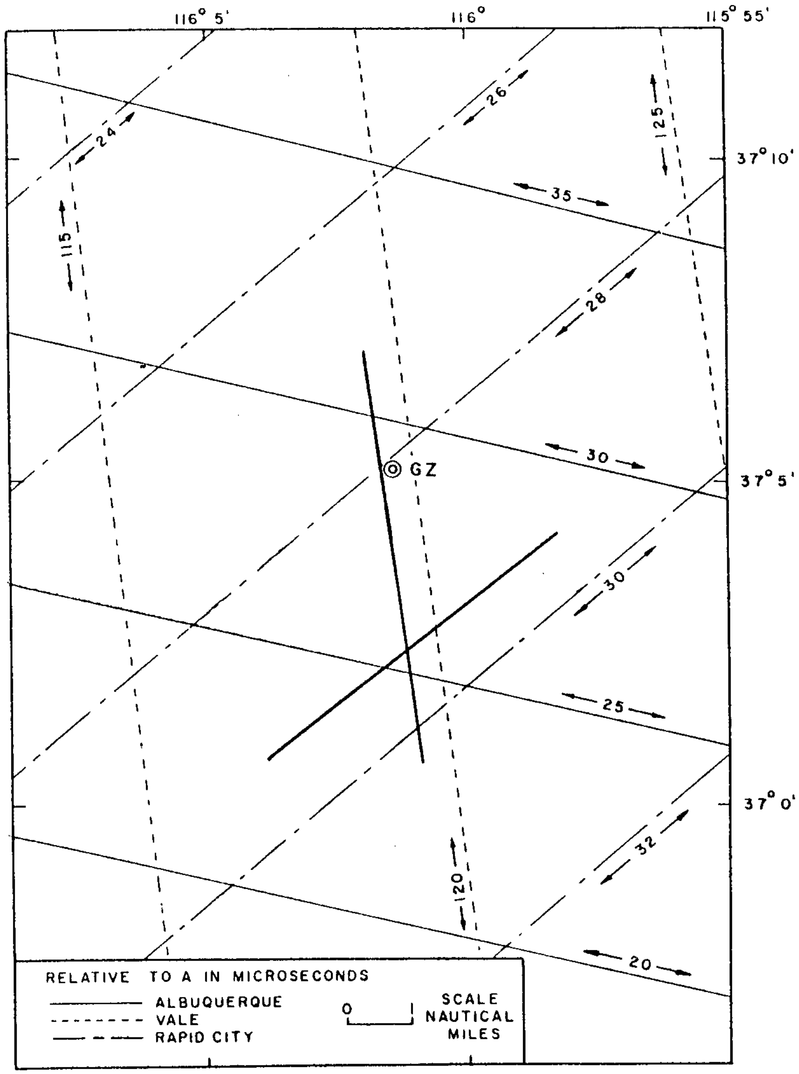


Figure A.9 Shot Doppler.

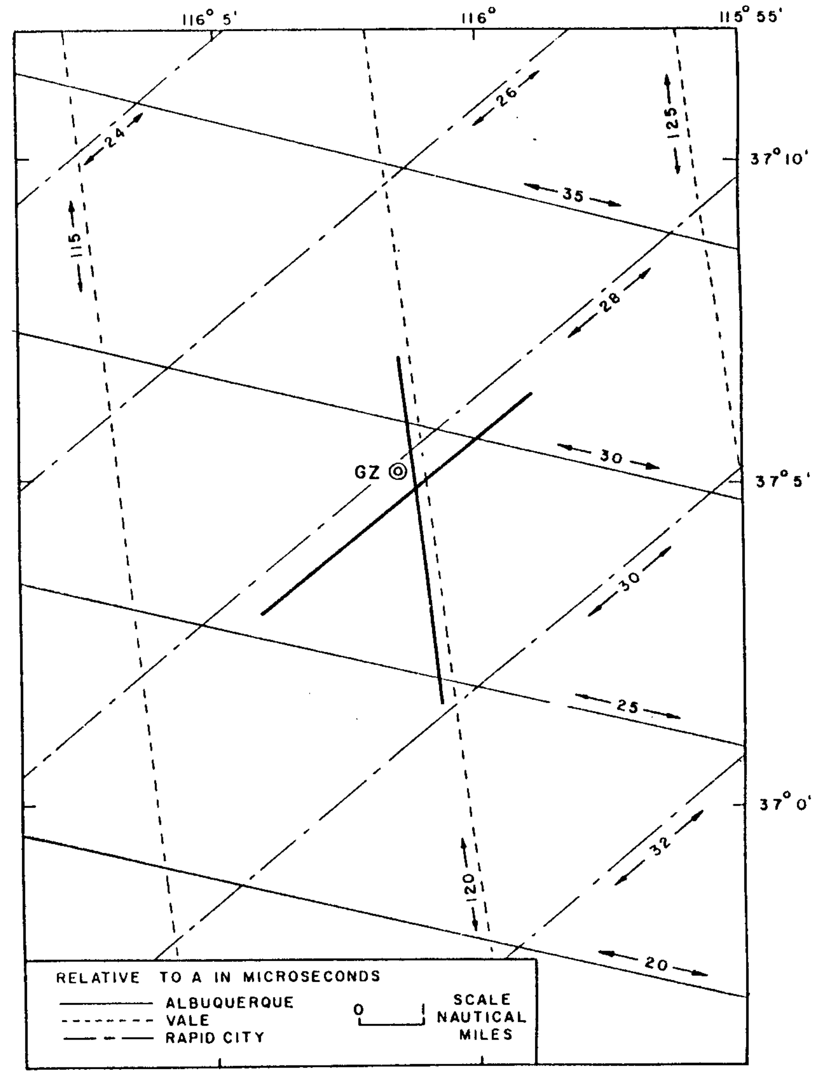


Figure A.10 Shot Franklin.



[redacted]

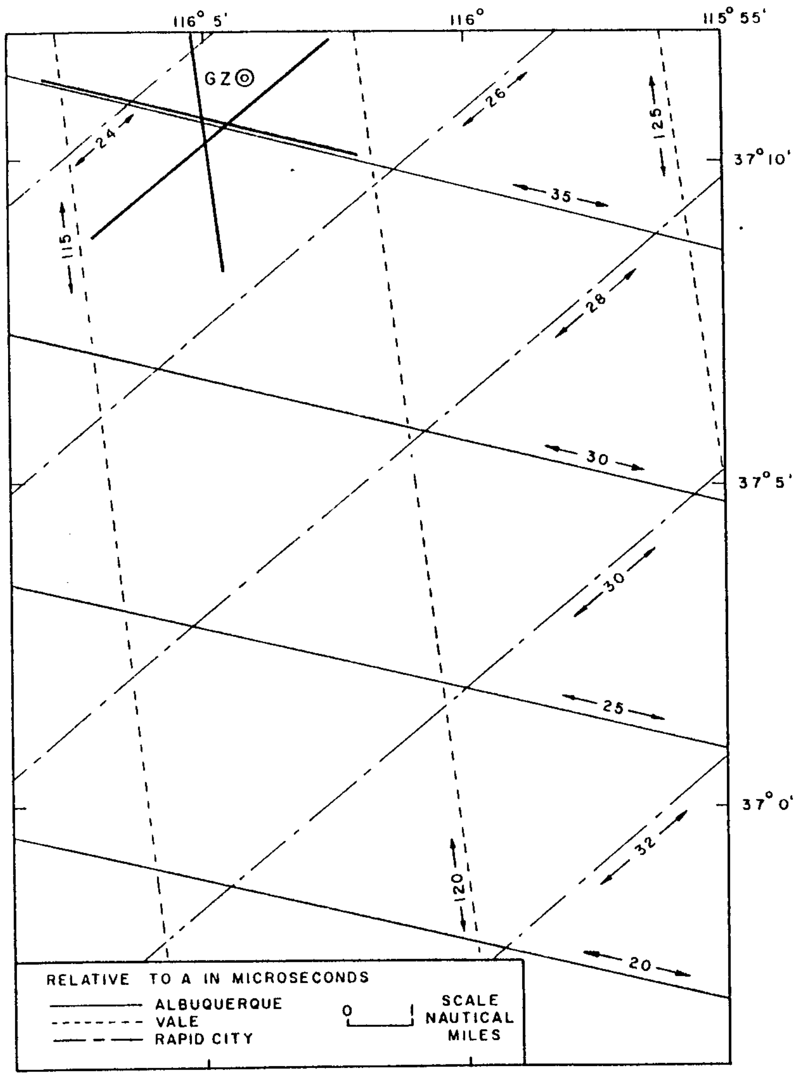


Figure A.11 Shot Smoky.

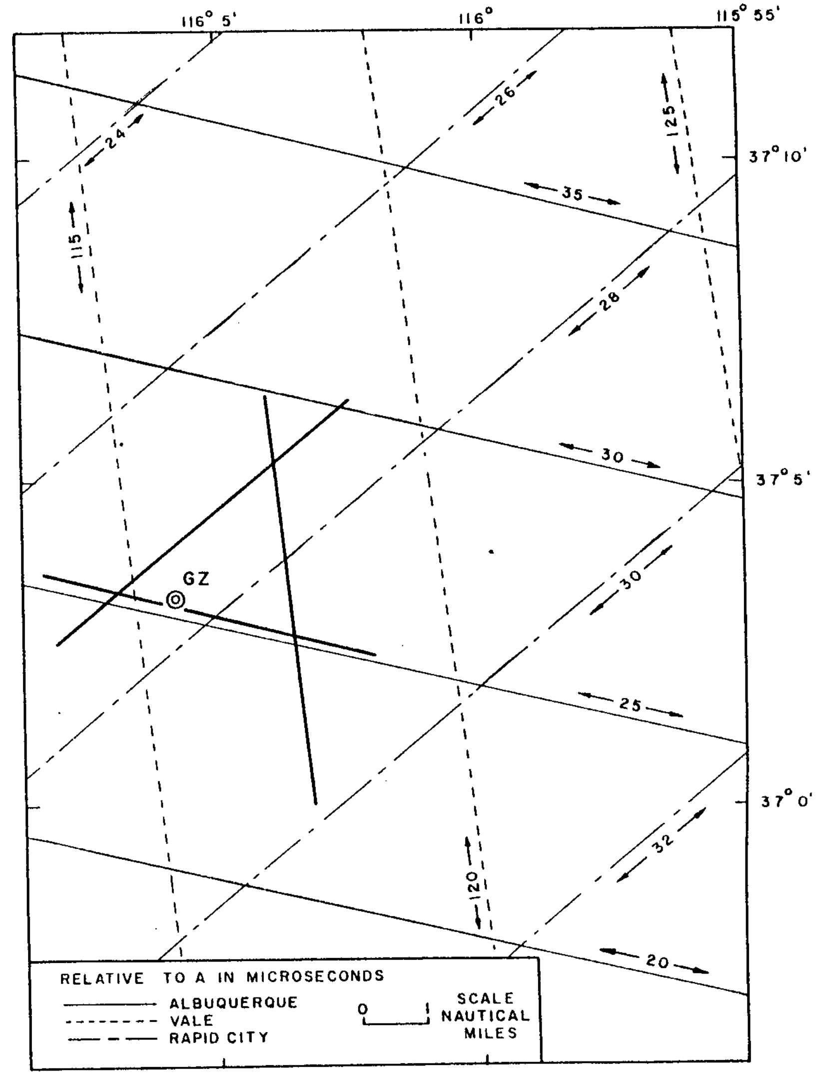


Figure A.12 Shot Galileo.



[redacted]

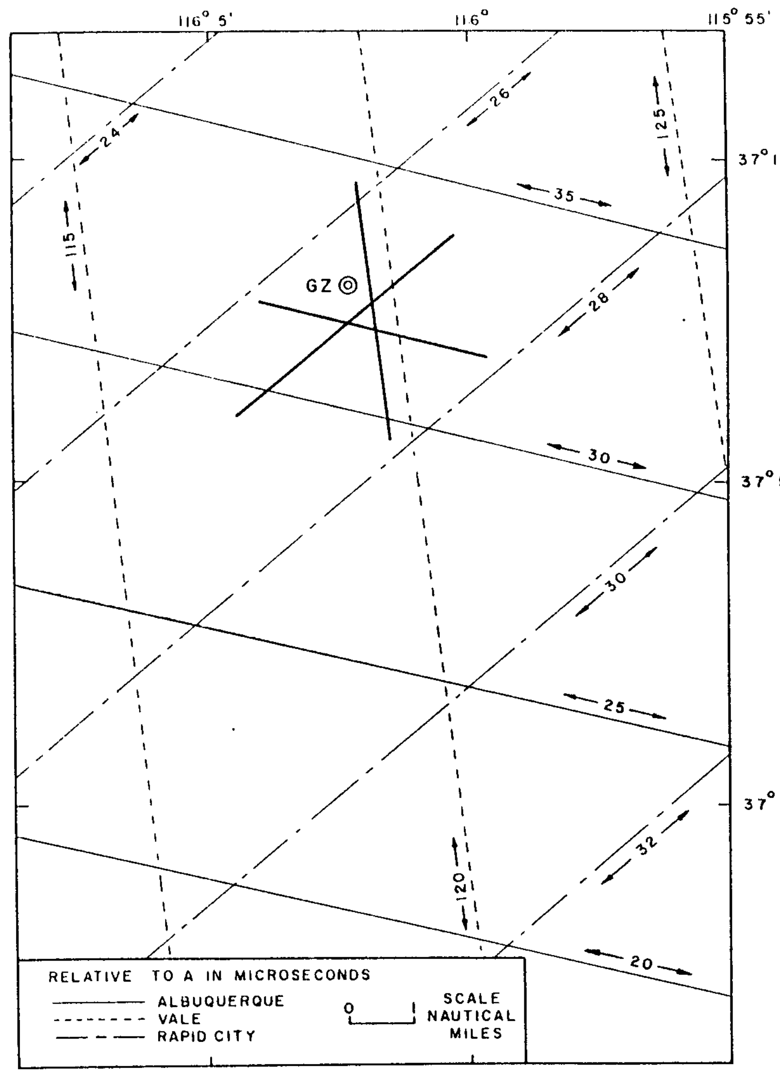


Figure A.13 Shot Wheeler.

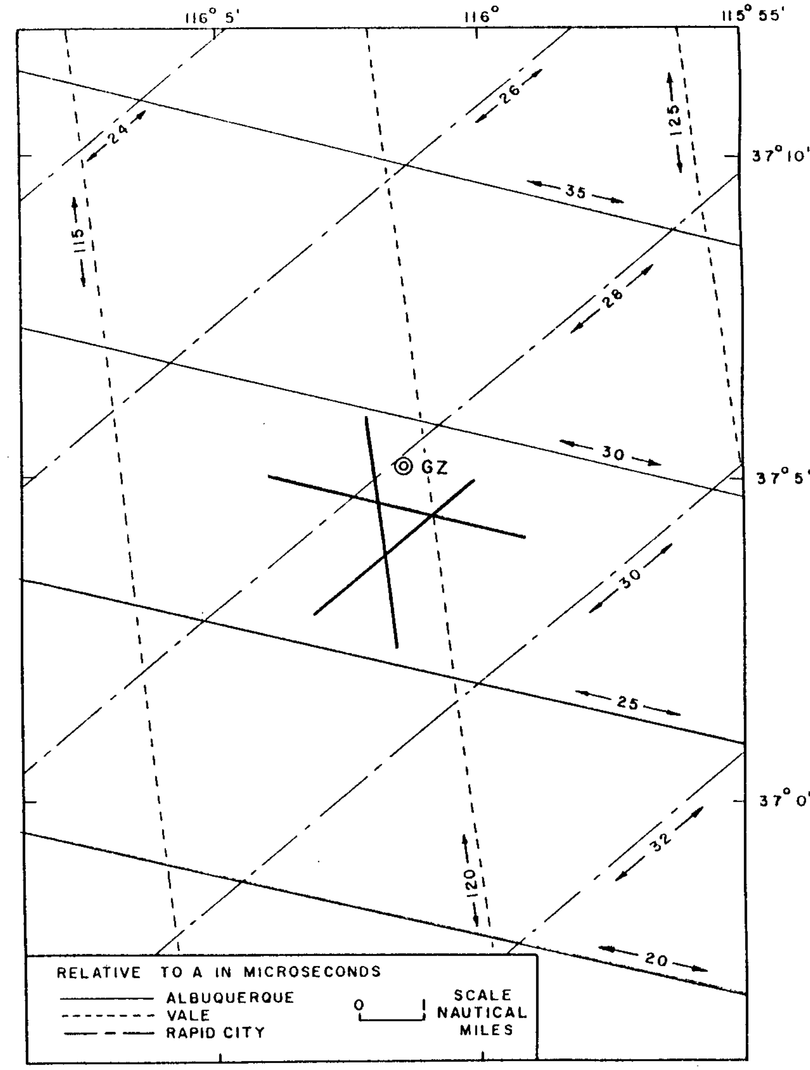


Figure A.14 Shot LaPlace.



[redacted]

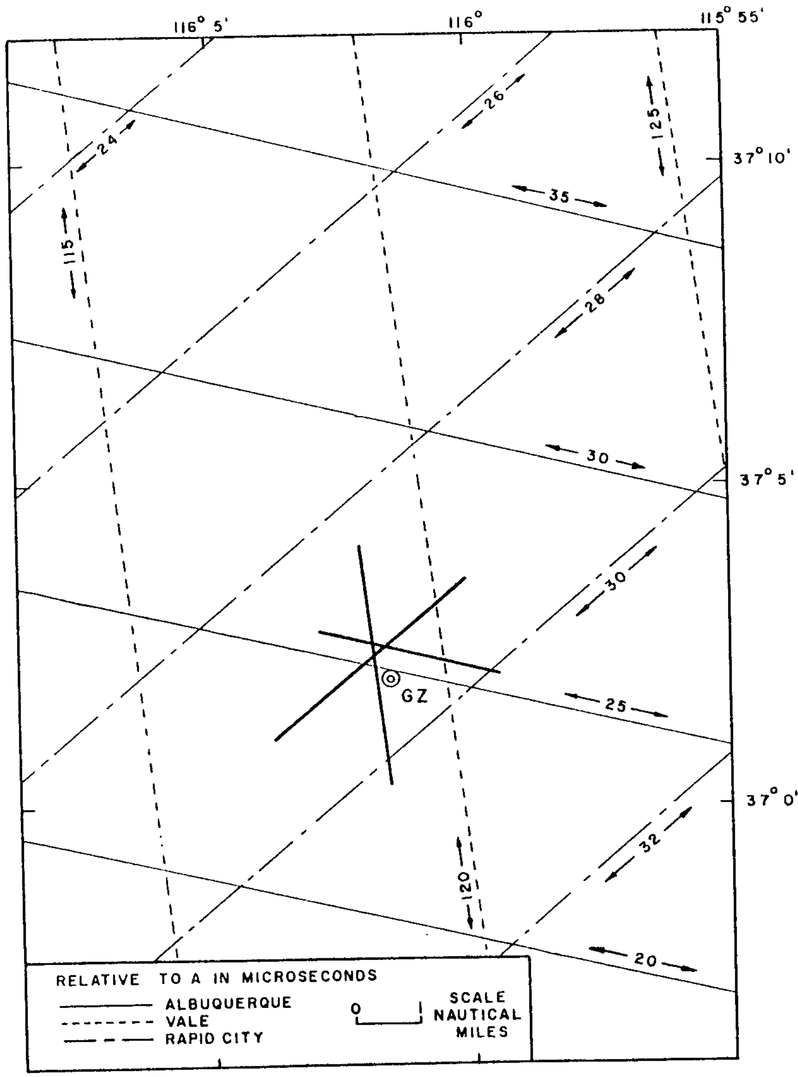


Figure A.15 Shot Fizeau.

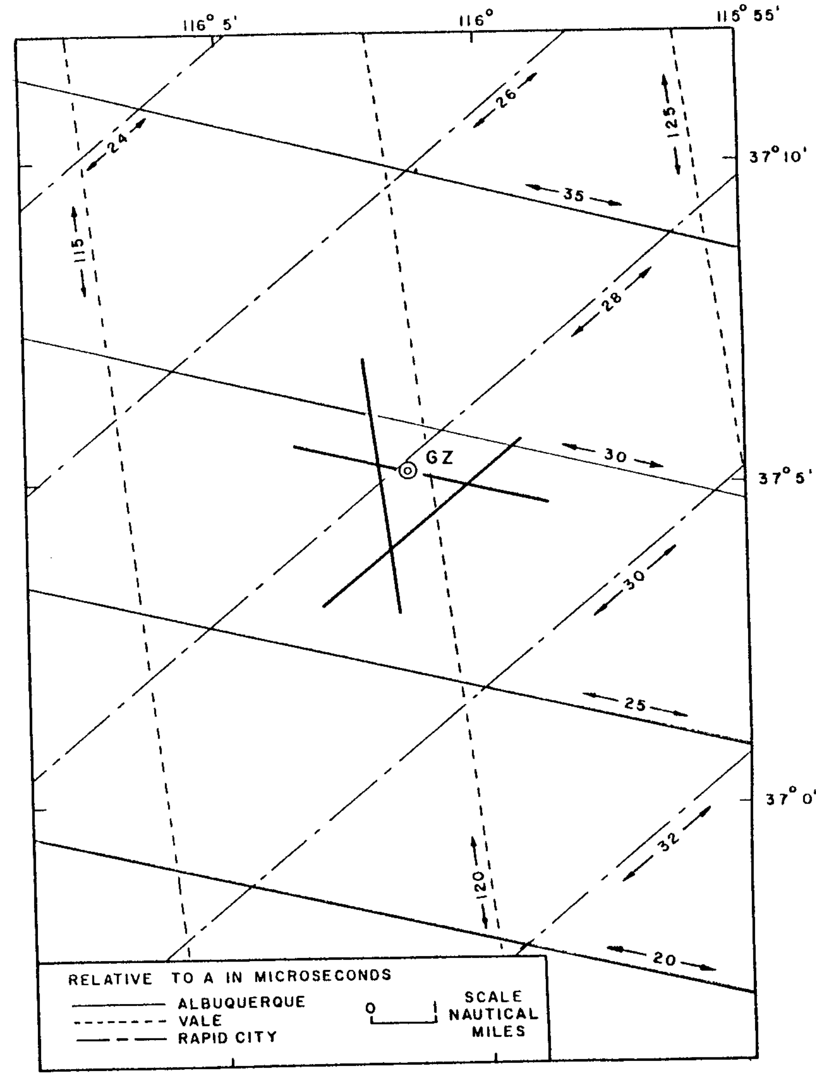


Figure A.16 Shot Newton.



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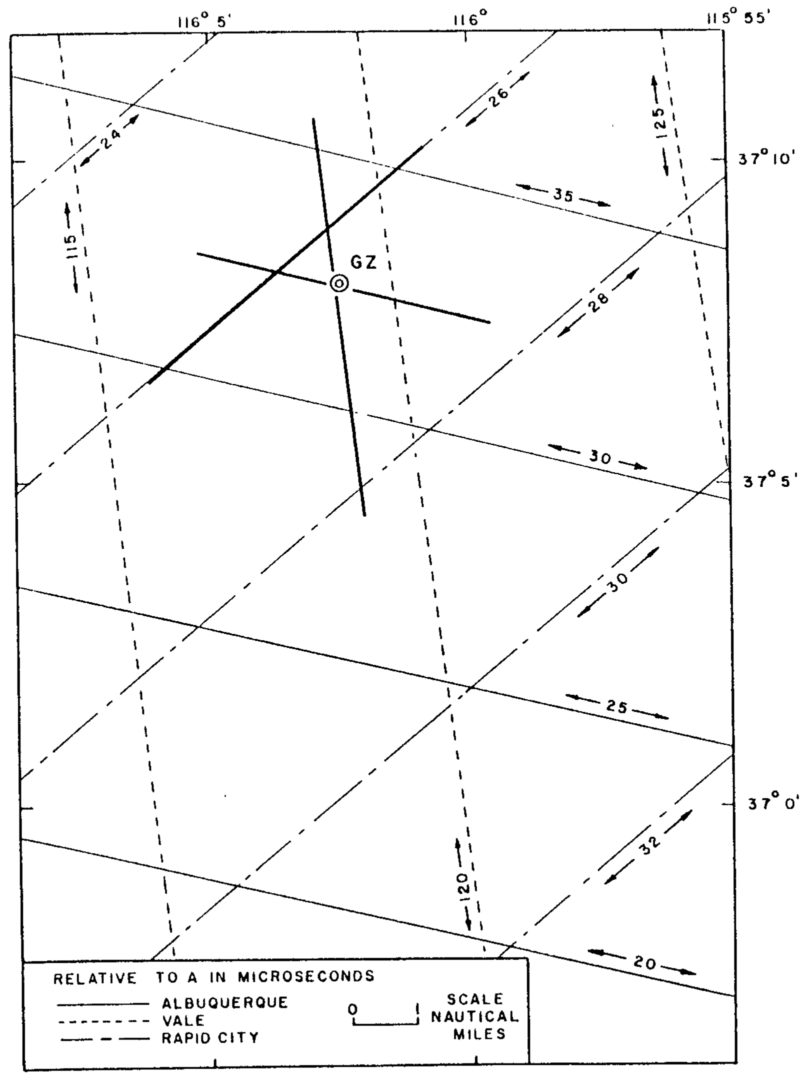


Figure A.17 Shot Charleston.

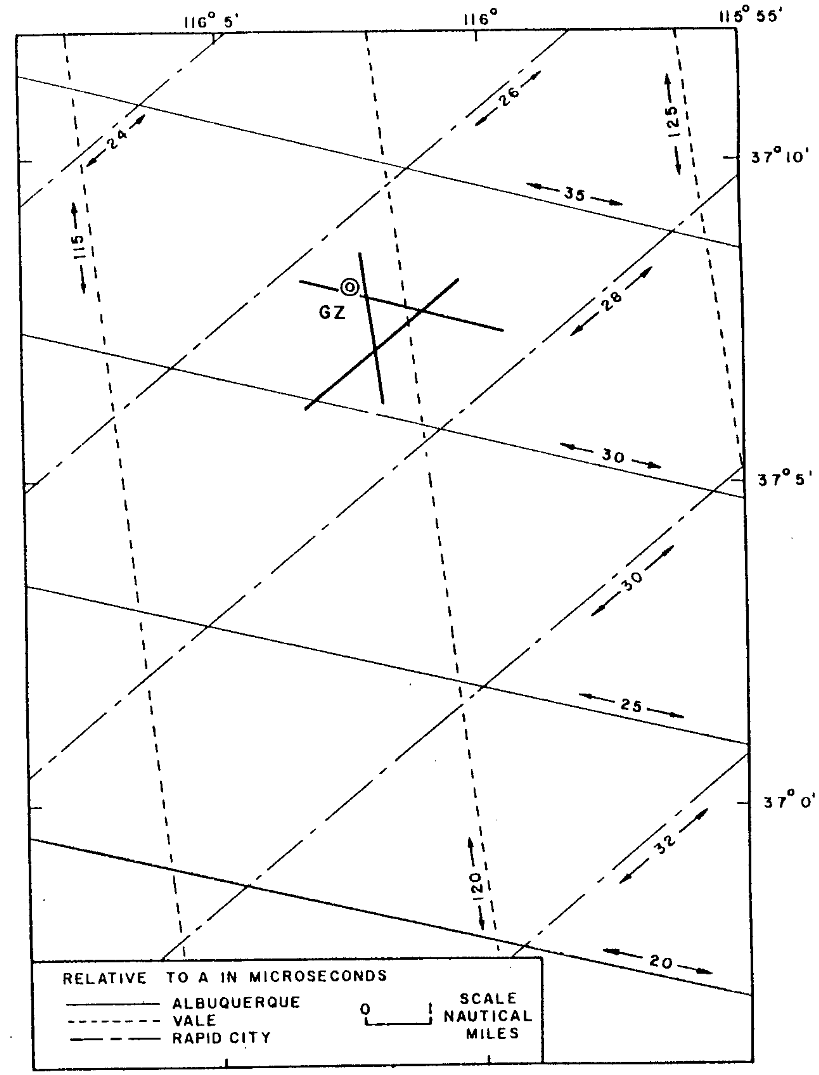


Figure A.18 Shot Morgan.

# APPENDIX B WAVEFORMS

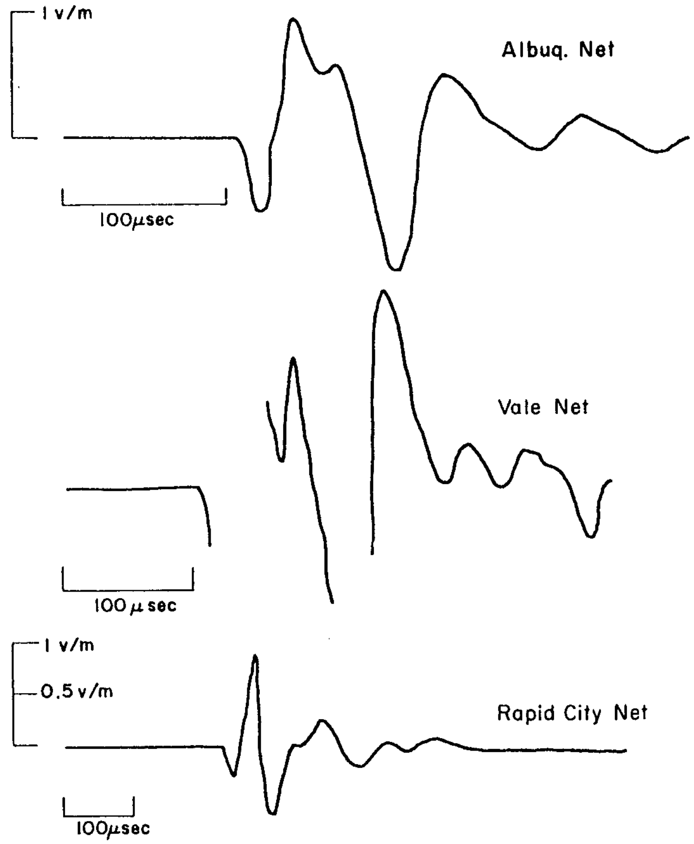


Figure B.1 Shot Wilson.

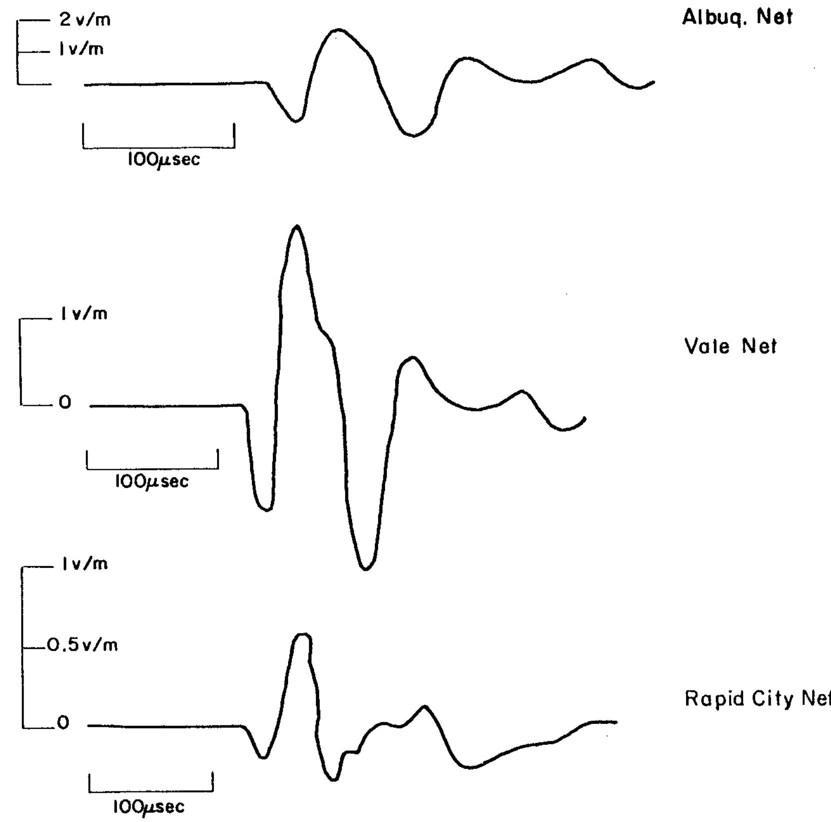


Figure B.2 Shot Priscilla.



[redacted]

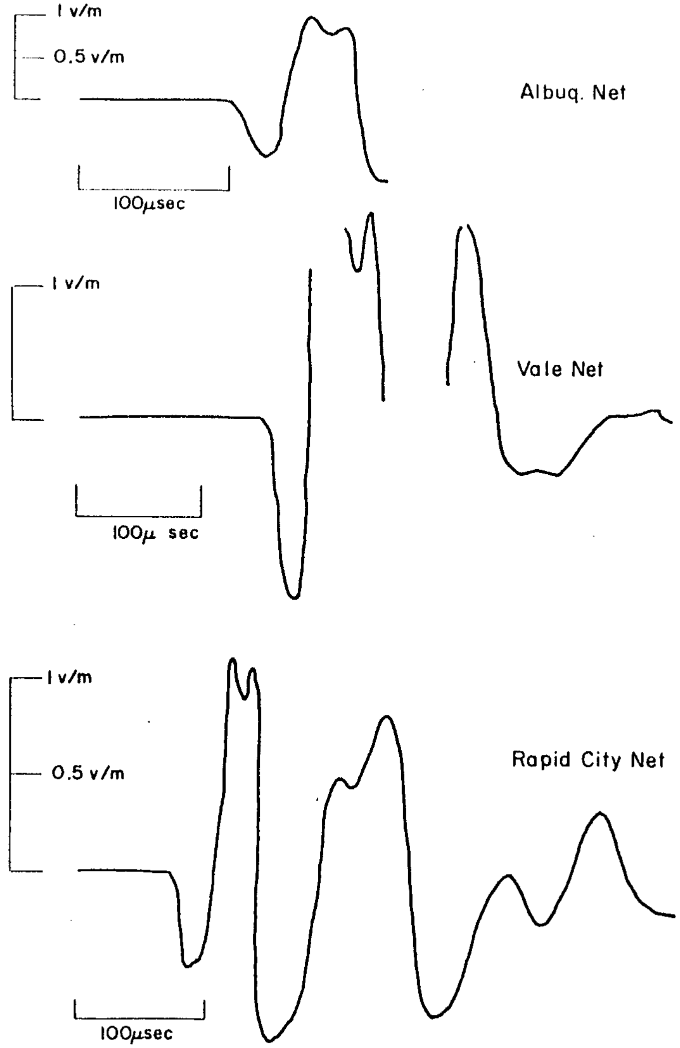


Figure B.3 Shot Hood.

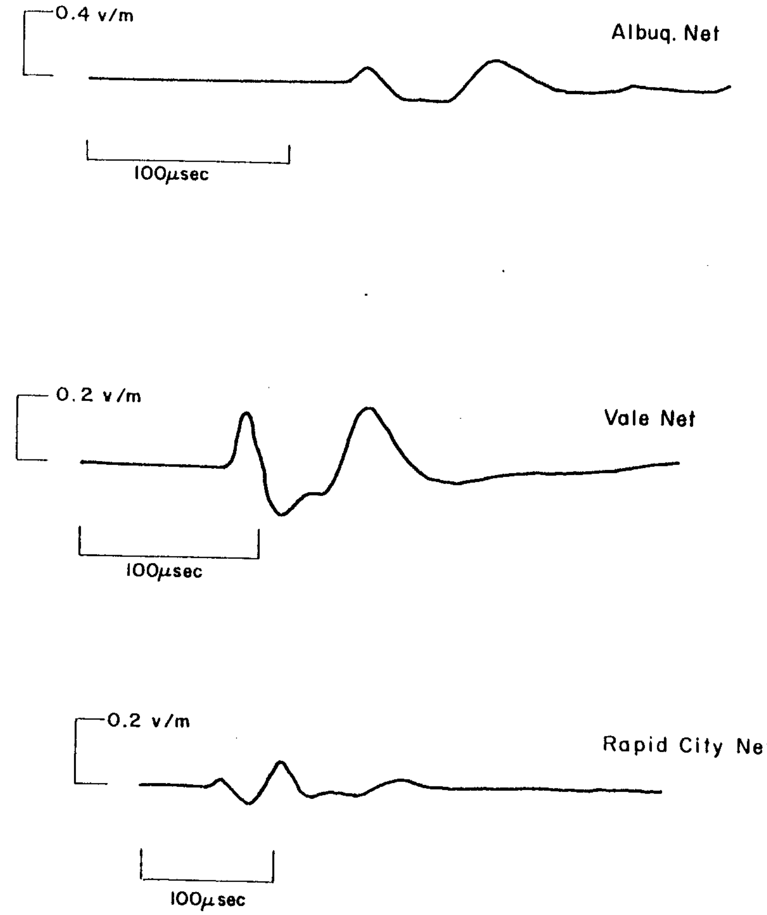


Figure B.4 Shot John.

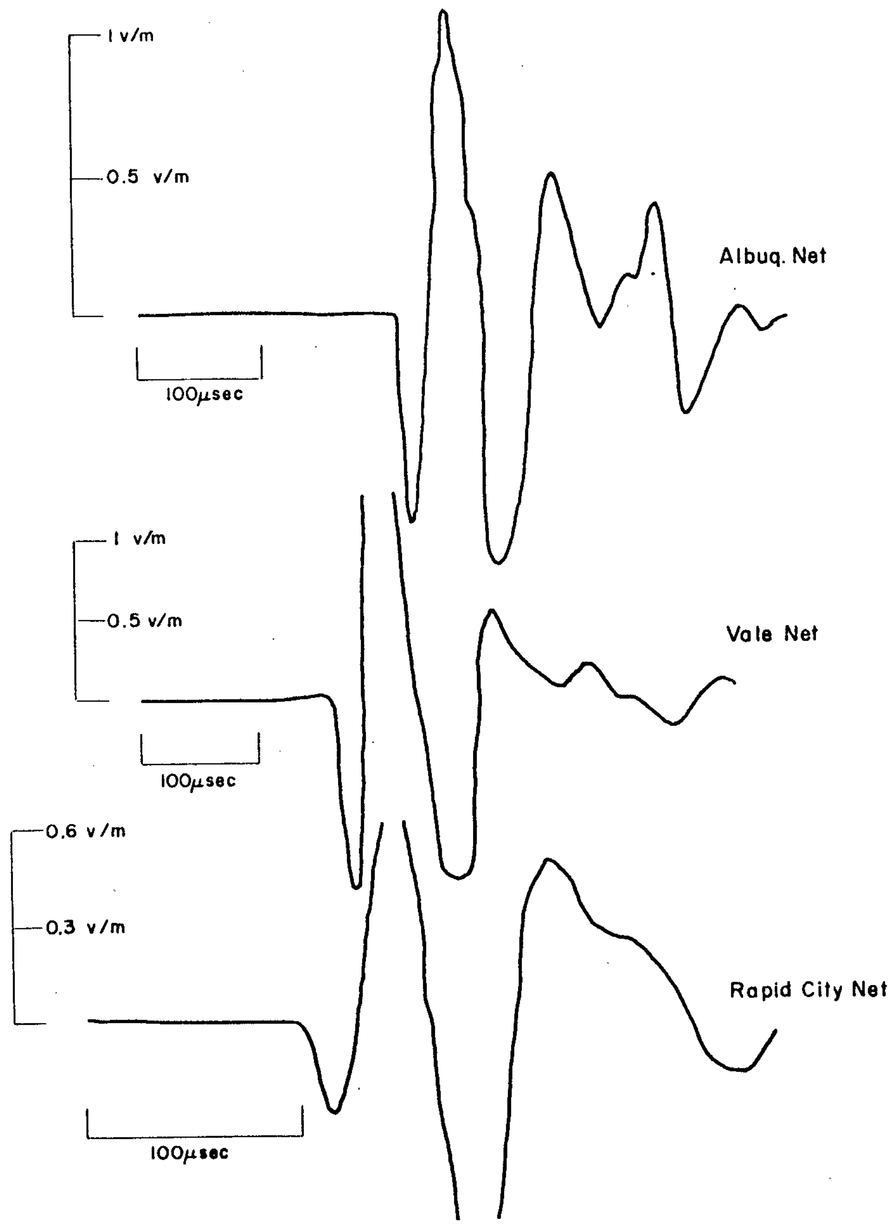


Figure B.5 Shot Owens.

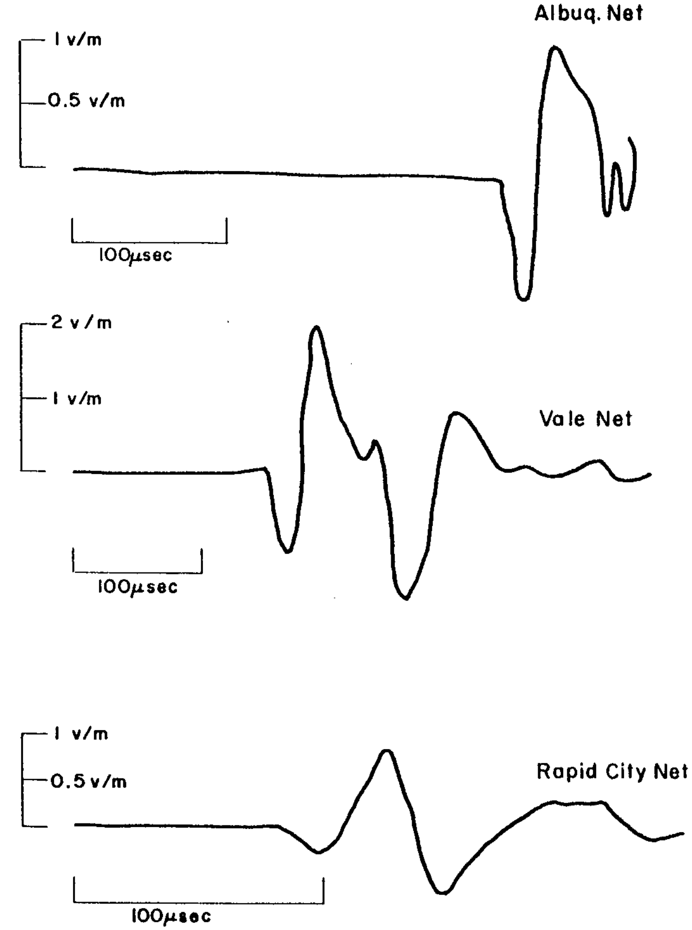


Figure B.6 Shot Stokes.



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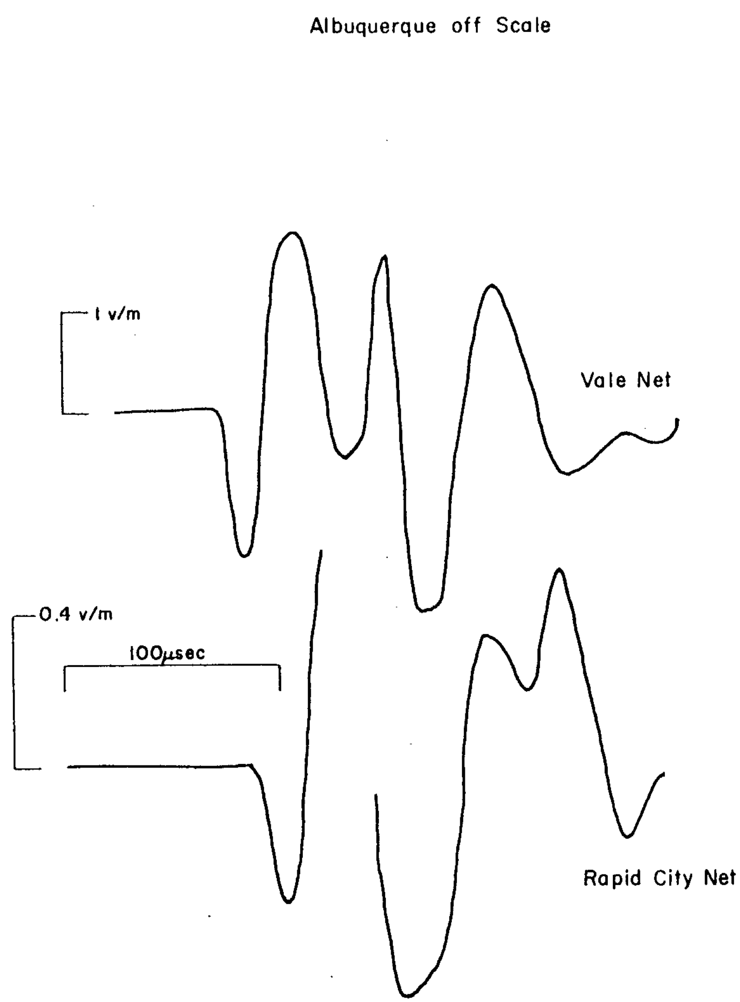


Figure B.7 Shot Doppler.

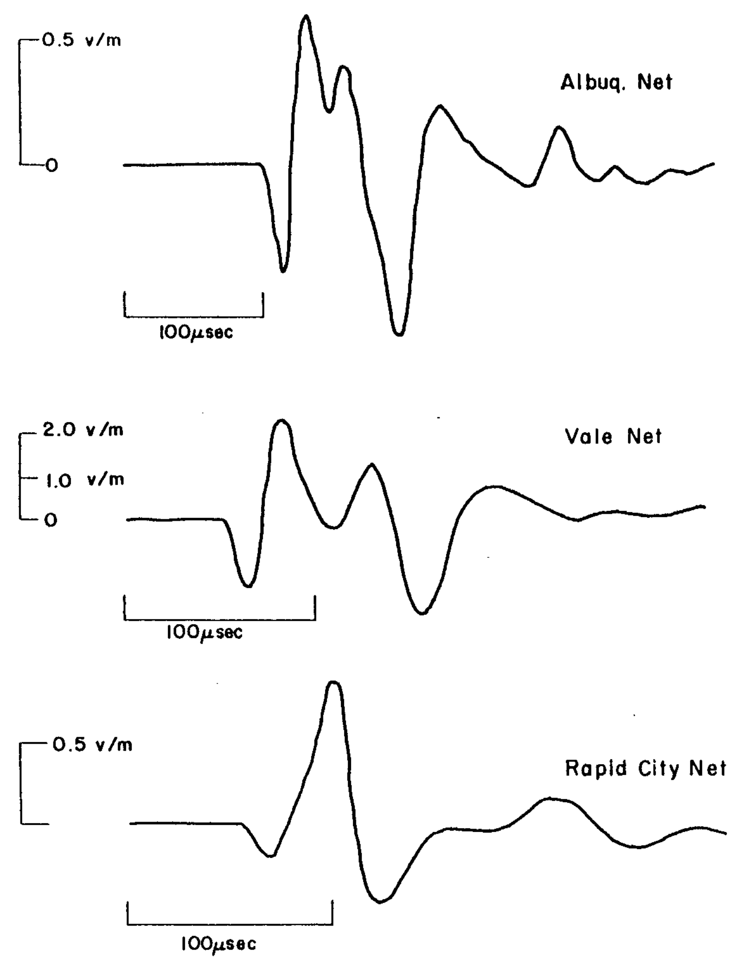


Figure B.8 Shot Franklin.



[redacted]

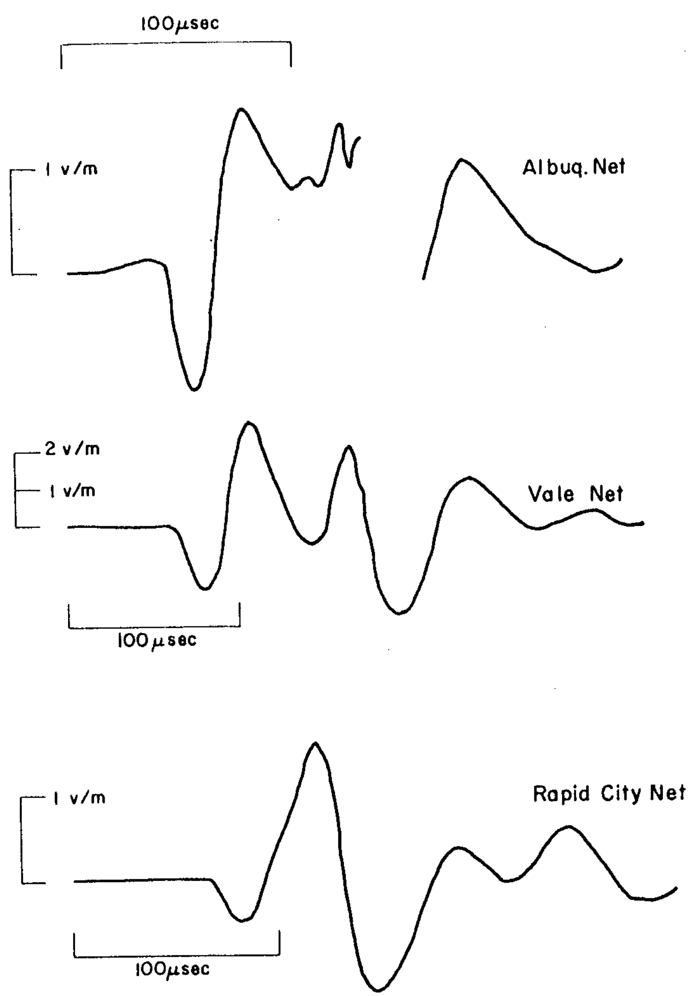


Figure B.9 Shot Smoky.

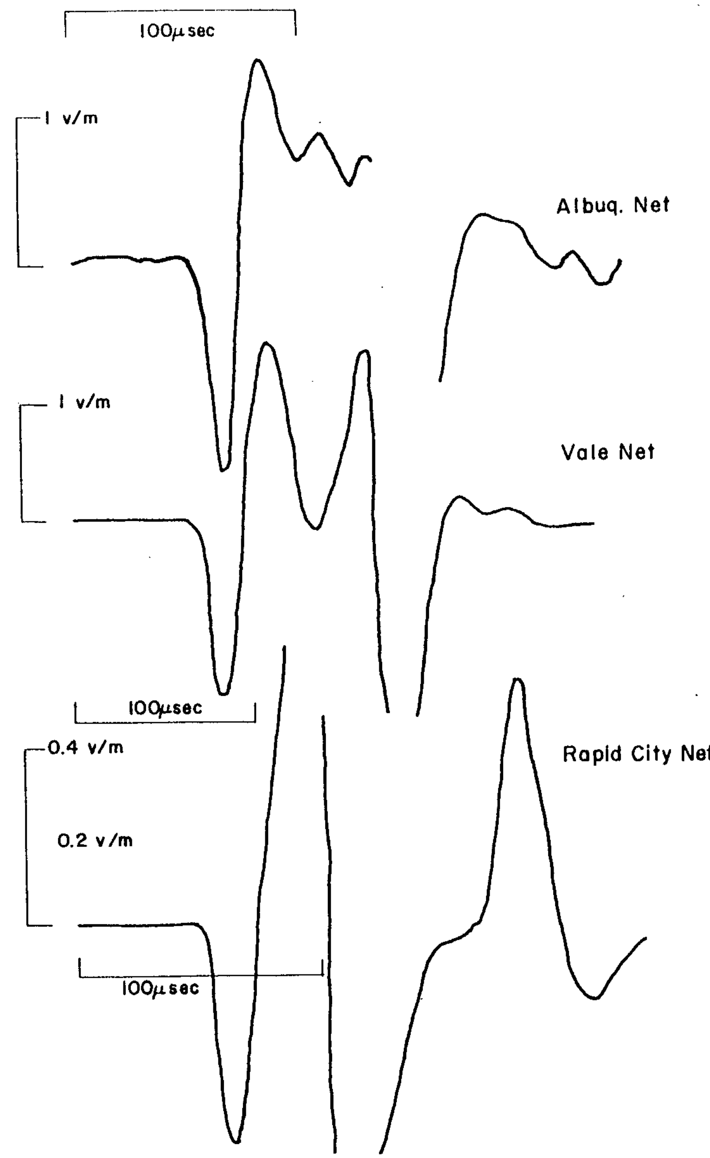


Figure B.10 Shot Galileo.



[redacted]

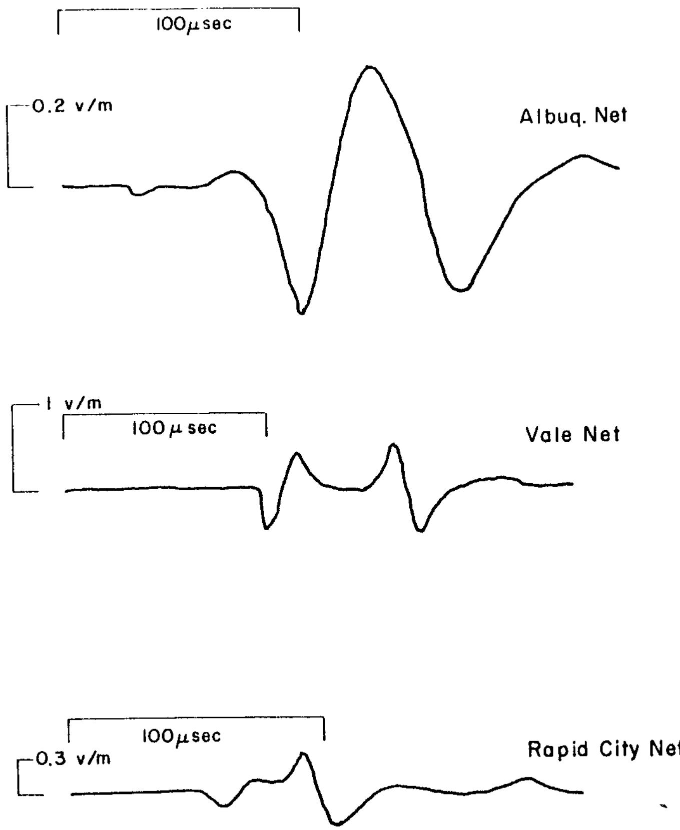


Figure B.11  Shot Wheeler.

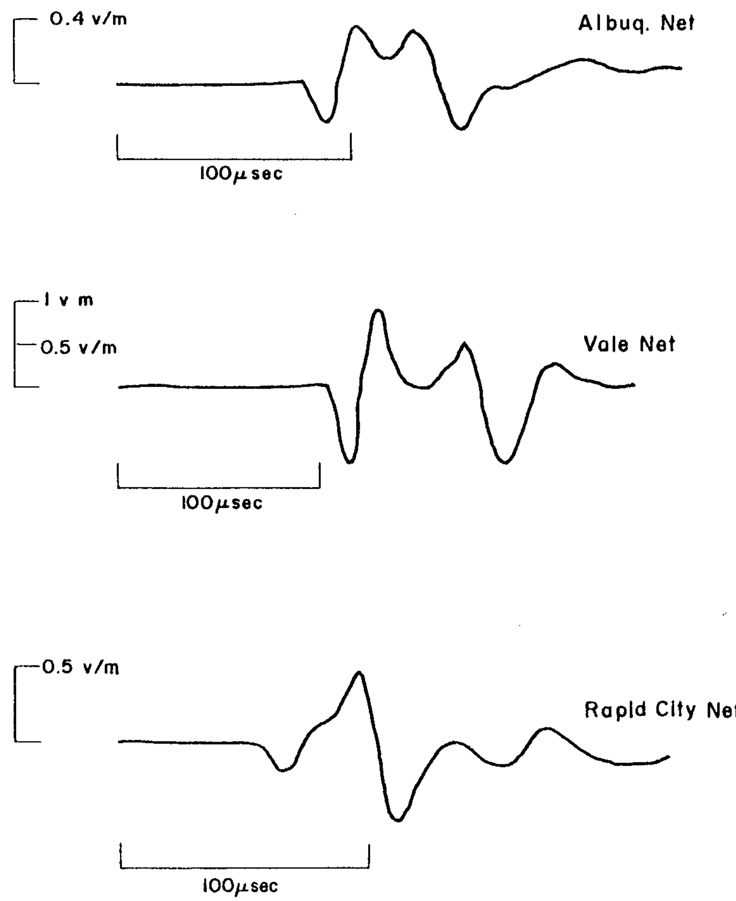


Figure B.12  Shot LaPlace.



[redacted]

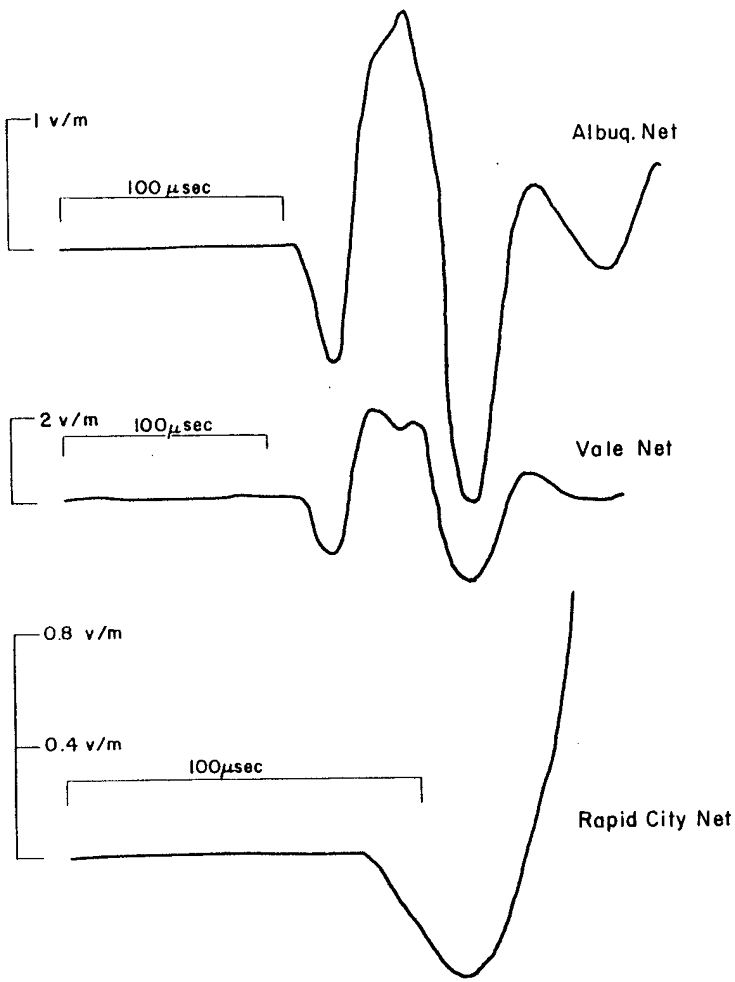


Figure B.13 Shot Fizeau.

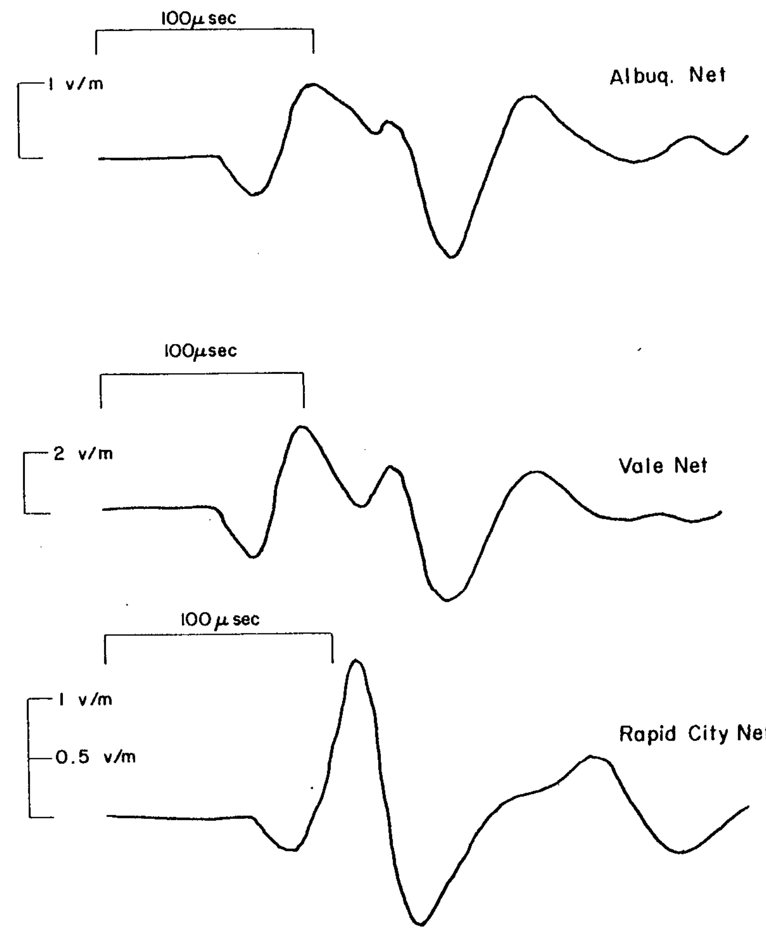


Figure B.14 Shot Newton.



[redacted]

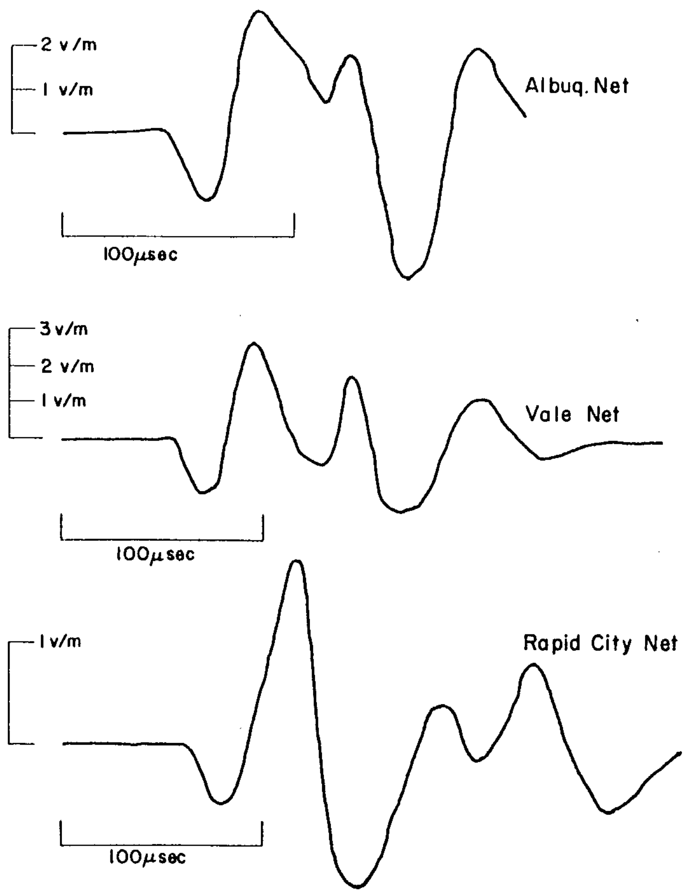


Figure B.15 Shot Charleston.

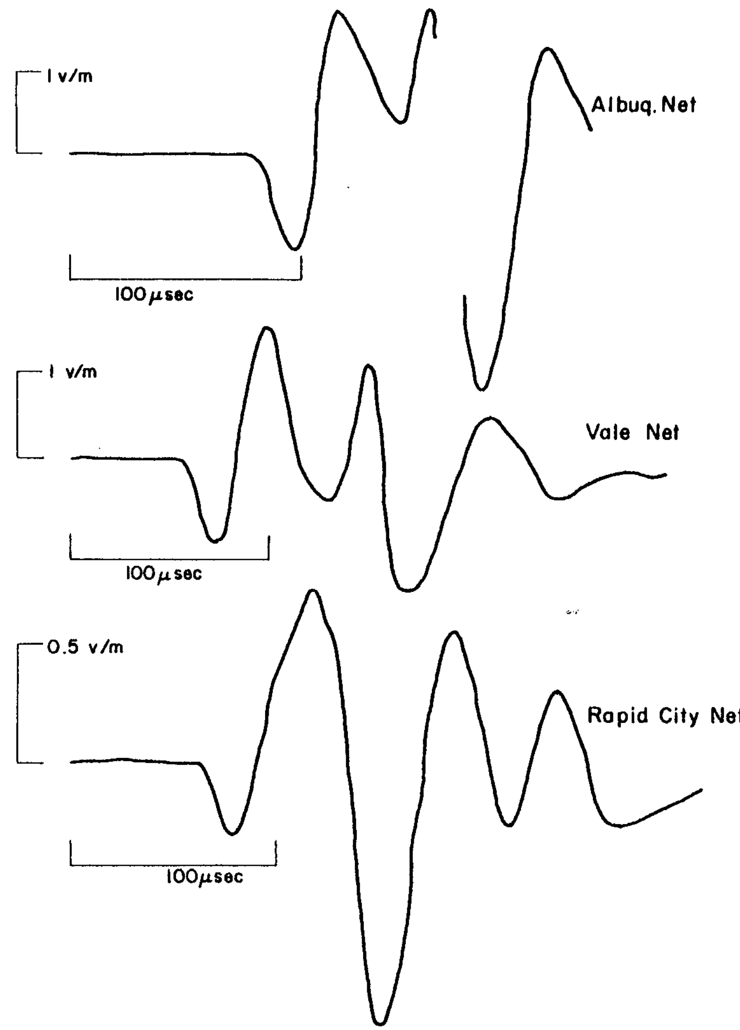


Figure B.16 Shot Morgan.



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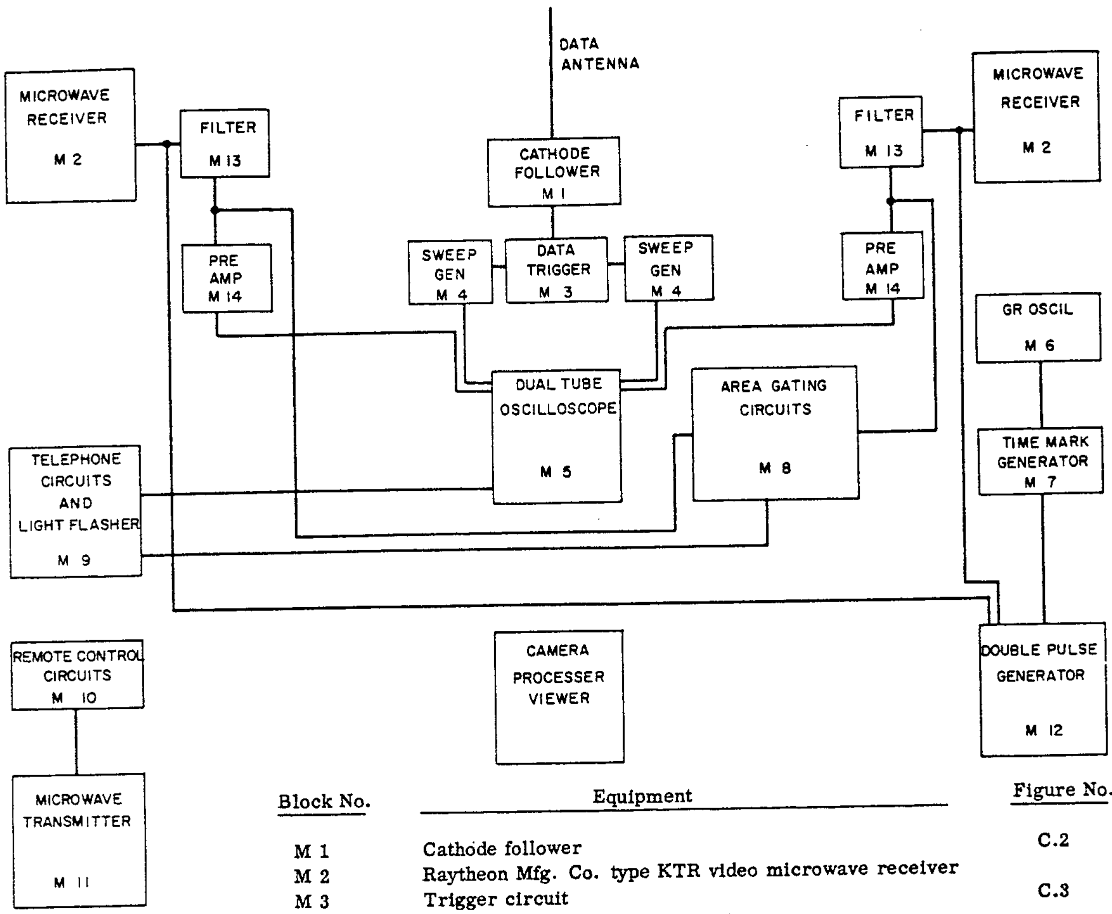
# APPENDIX C

# SYSTEM SCHEMATICS




| Block No. | Equipment | Figure No. |
|---|---|---|
| M 1 | Cathode follower | C.2 |
| M 2 | Raytheon Mfg. Co. type KTR video microwave receiver | |
| M 3 | Trigger circuit | C.3 |
| M 4 | Tektronix 162 waveform generator | |
| M 5 | Laboratory-built dual tube oscilloscope | C.4 |
| M 6 | General Radio 1100A frequency standard | |
| M 7 | Time mark circuits | C.5 |
| M 8 | Area gate circuits | C.6 |
| M 9 | Telephone circuits and light flasher | C.7 |
| M 10 | Slave test circuits | C.8 |
| M 11 | Raytheon Mfg. Co. KTR 1000A (R) transmitter | |
| M 12 | Berkeley Type 1004 double pulse generator | |
| M 13 | Data filter | C.9 |
| M 14 | Tektronix Type 121 preamplifier | |

Figure C.1 Master station equipment block diagram.



[redacted]

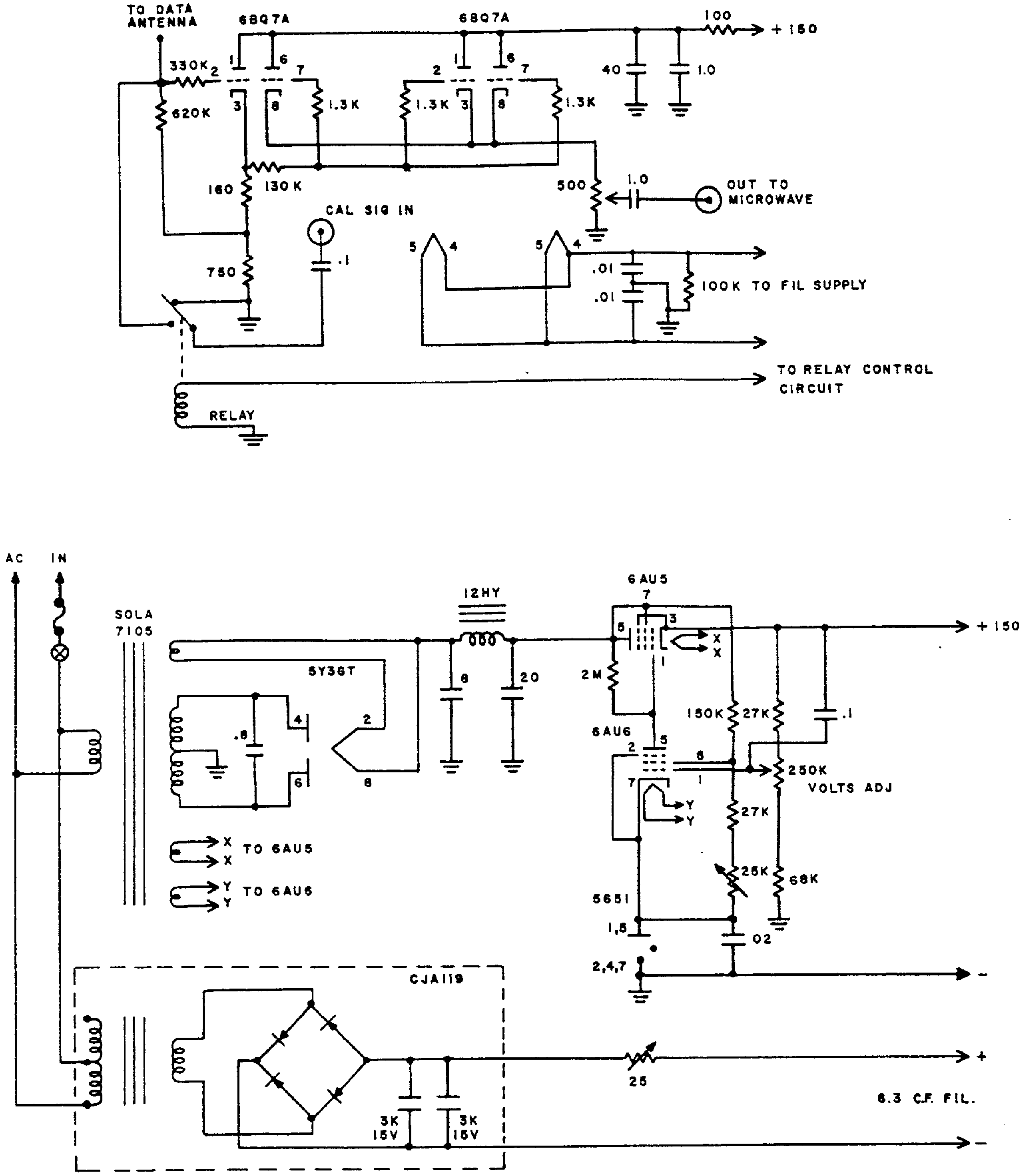



Figure C.2 Cathode follower (top) and power supply (bottom); (see Block M1, Figure C.1).



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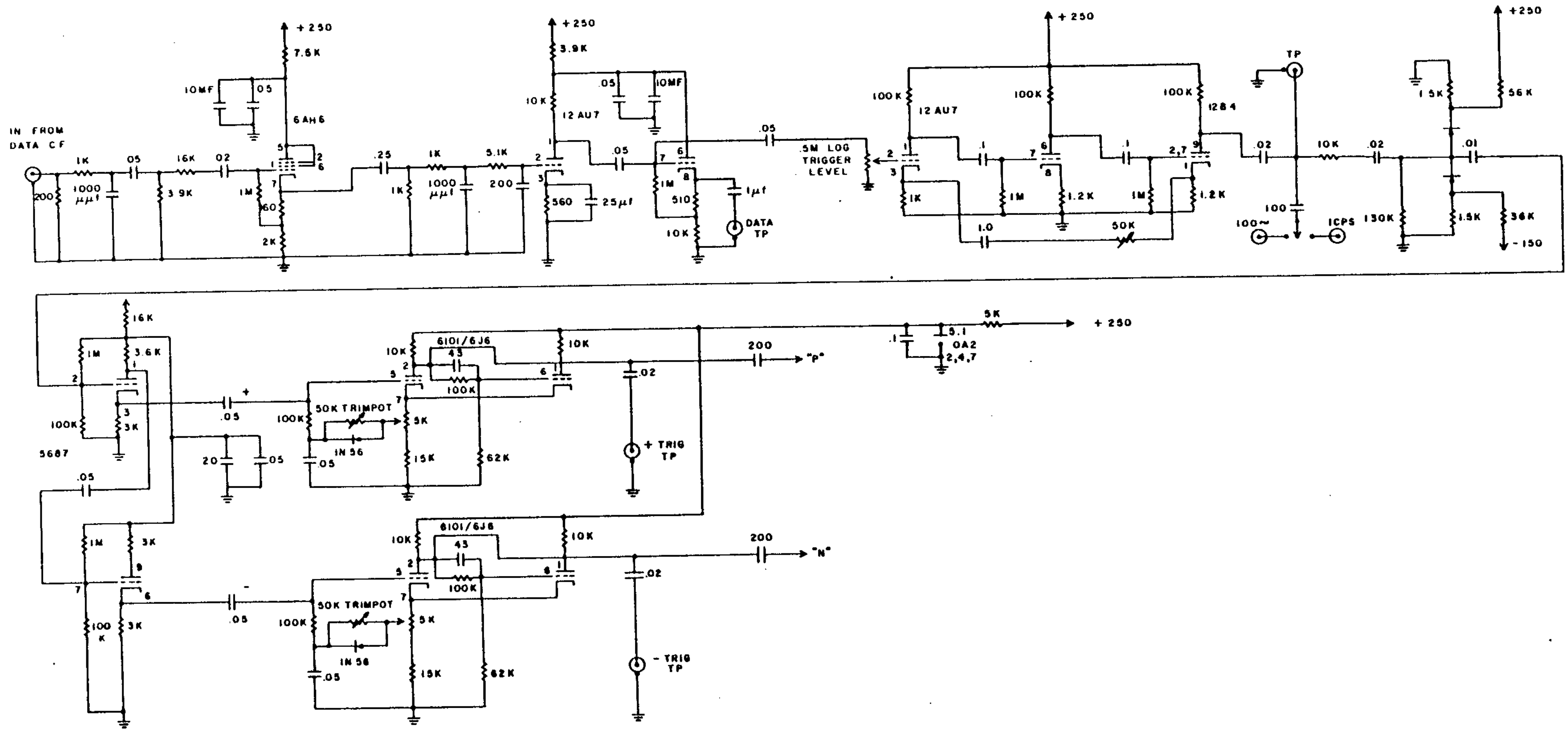


Figure C.3 Data trigger (see Block M3, Figure C.1).



[redacted]

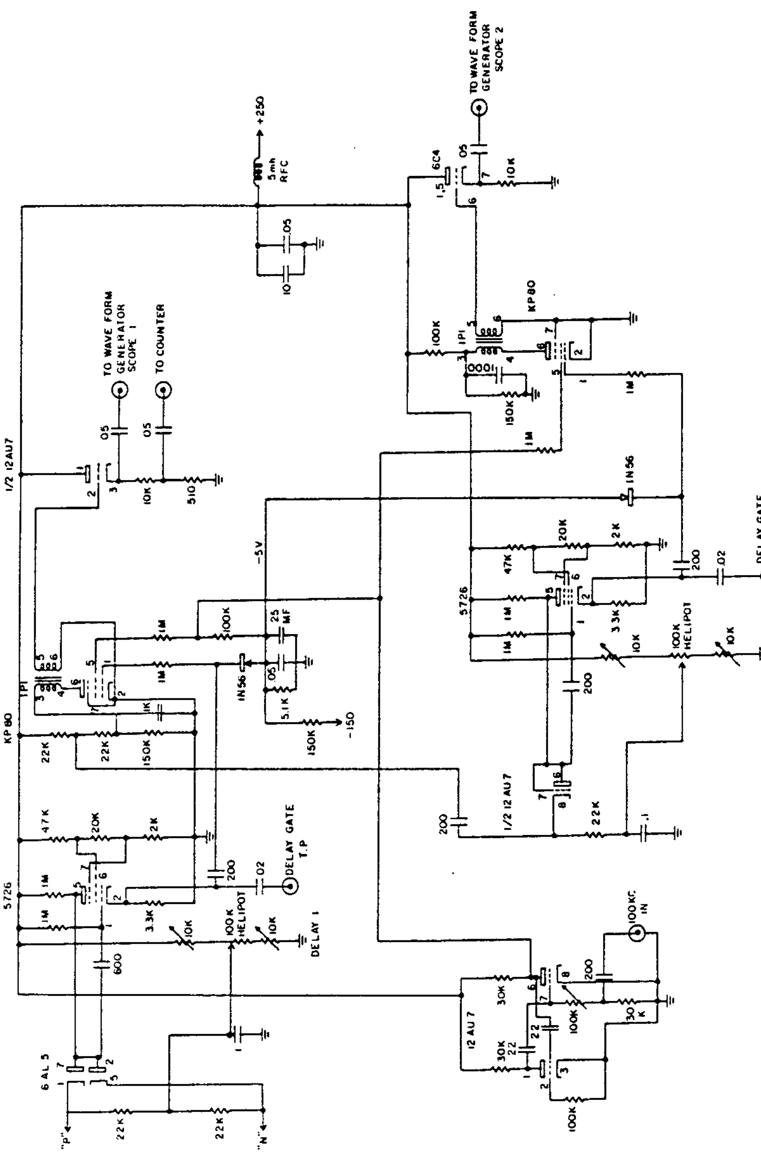


Figure C.3 continued.



[redacted]

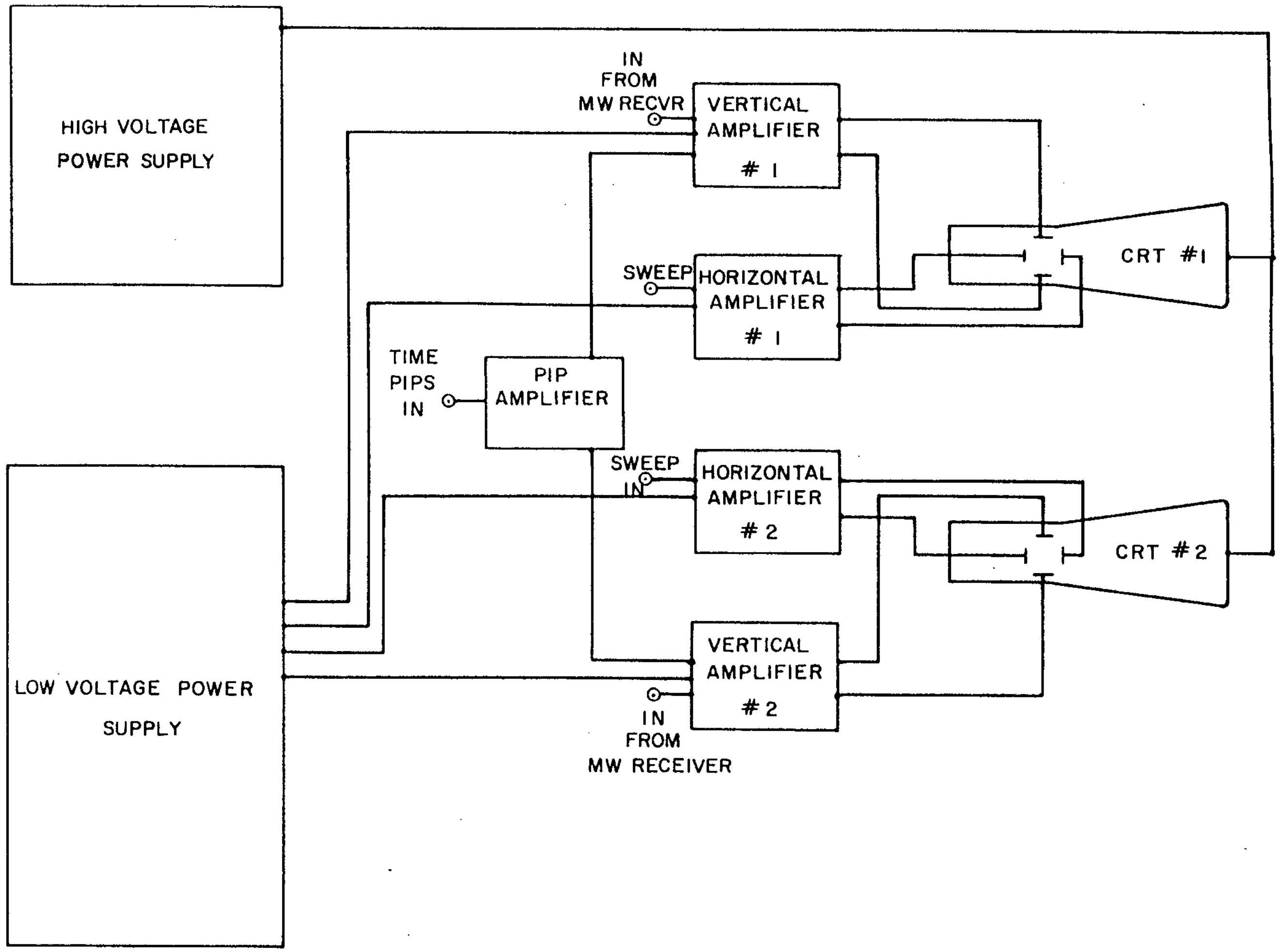


Figure C.4 Dual tube oscilloscope block diagram.



[redacted]

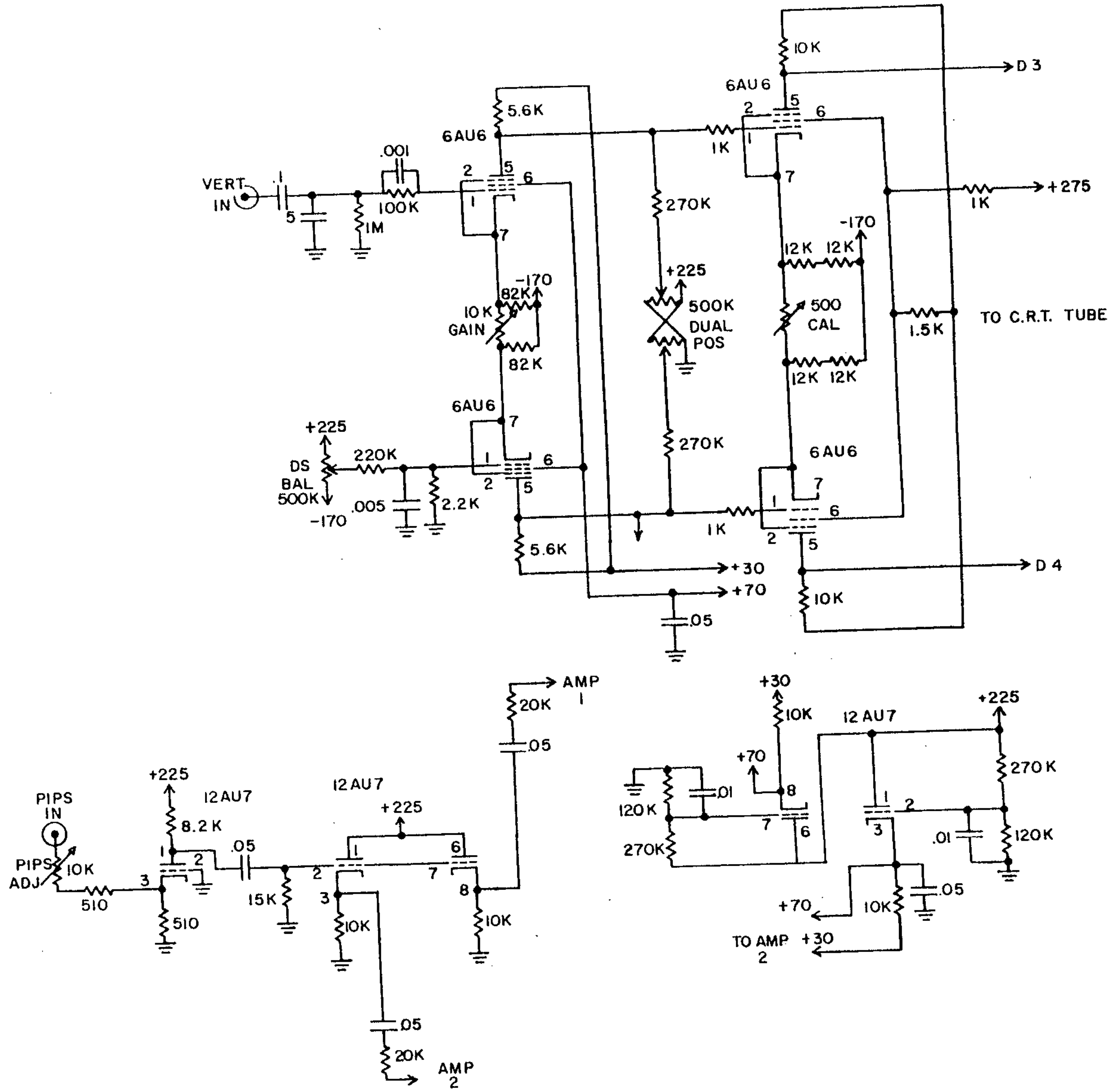


Figure C.4 continued. Dual tube oscilloscope, vertical amplifier No. 1 (No. 2 similar).



[redacted]

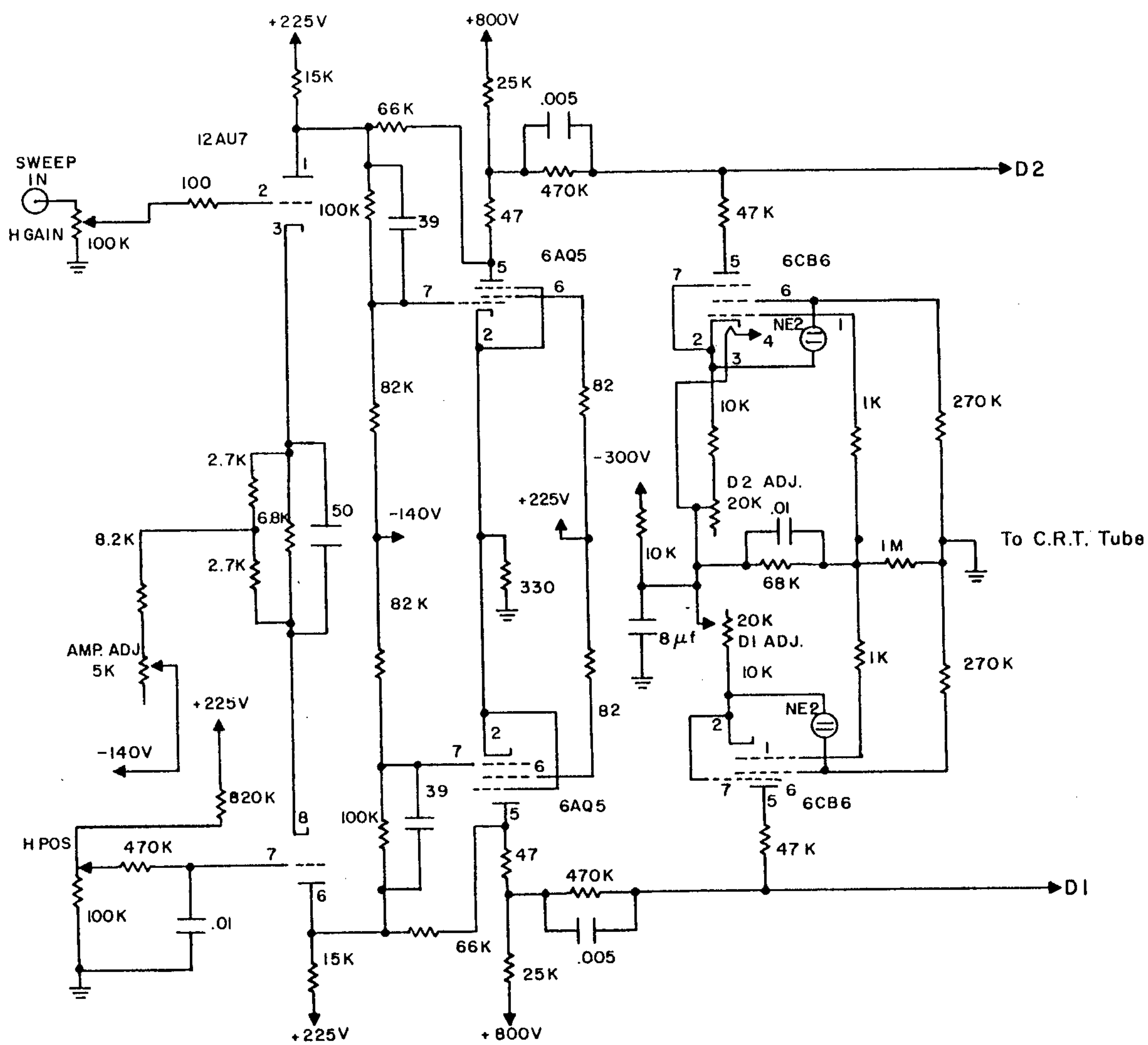


Figure C.4 continued. Dual oscilloscope, horizontal amplifier No. 1 ( No. 2 identical).



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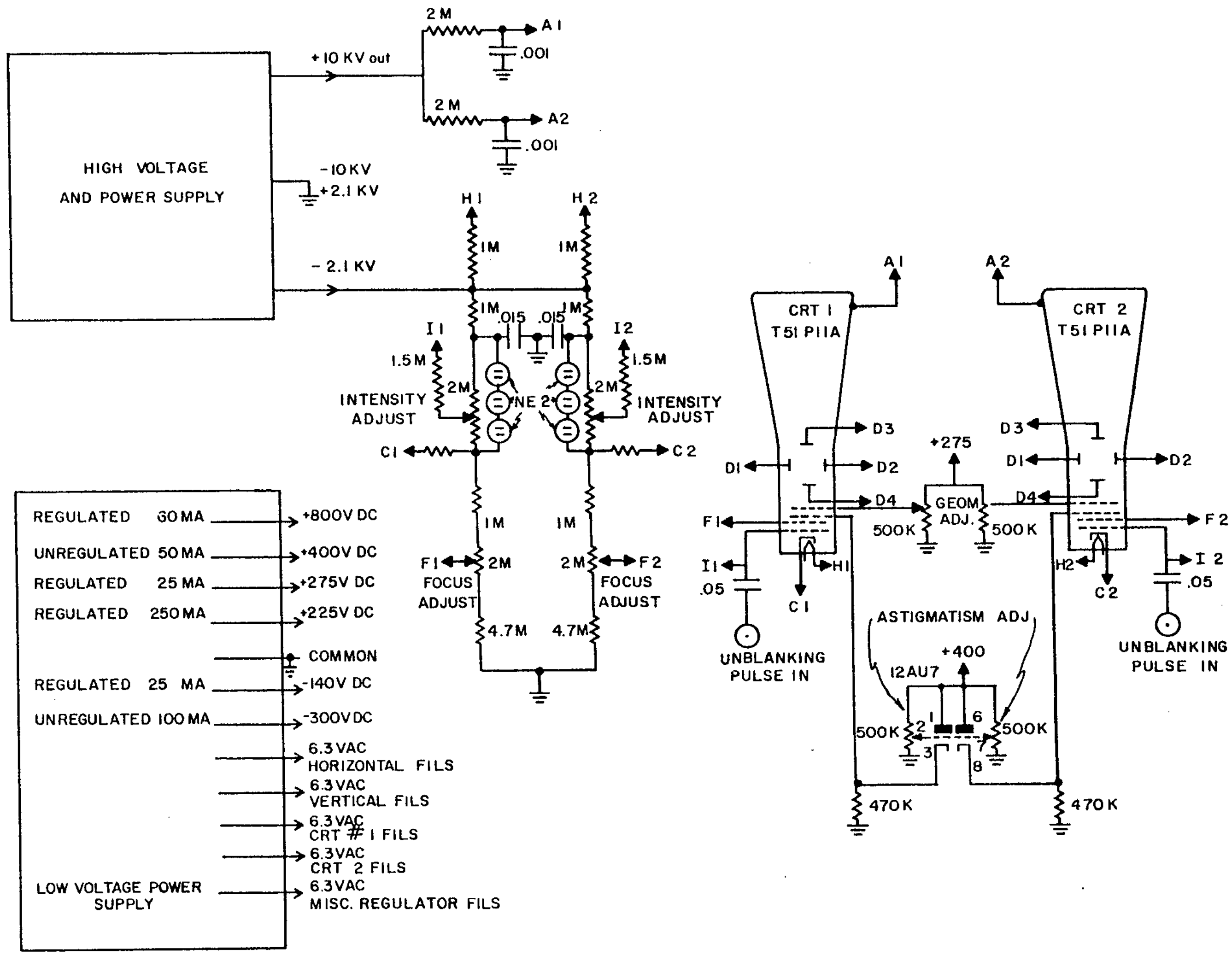



Figure C.4 continued. Dual tube oscilloscope, CRT tube circuits and power supply requirements.



[redacted]

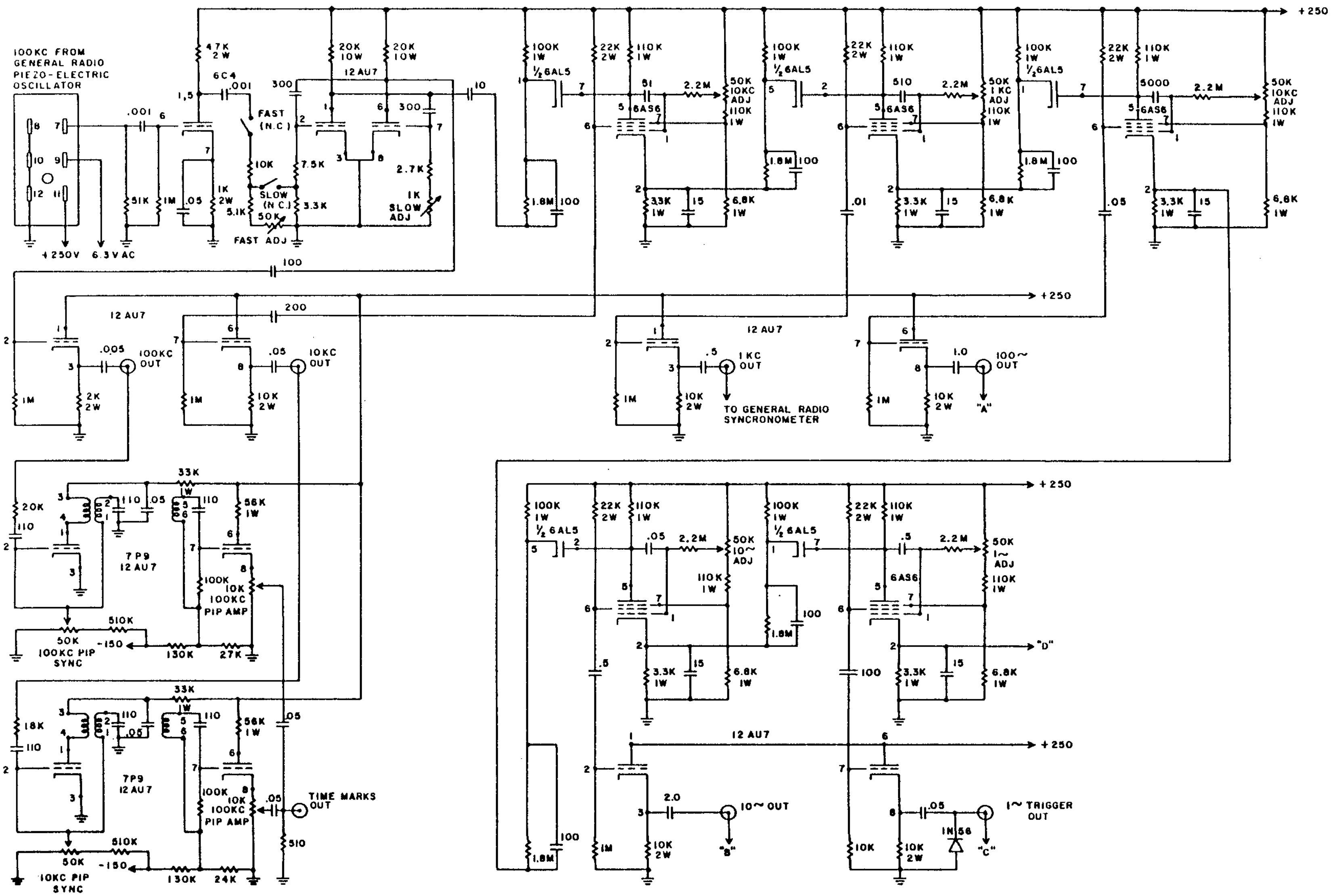



Figure C.5 World time mark generator (see Block M7, Figure C.1).

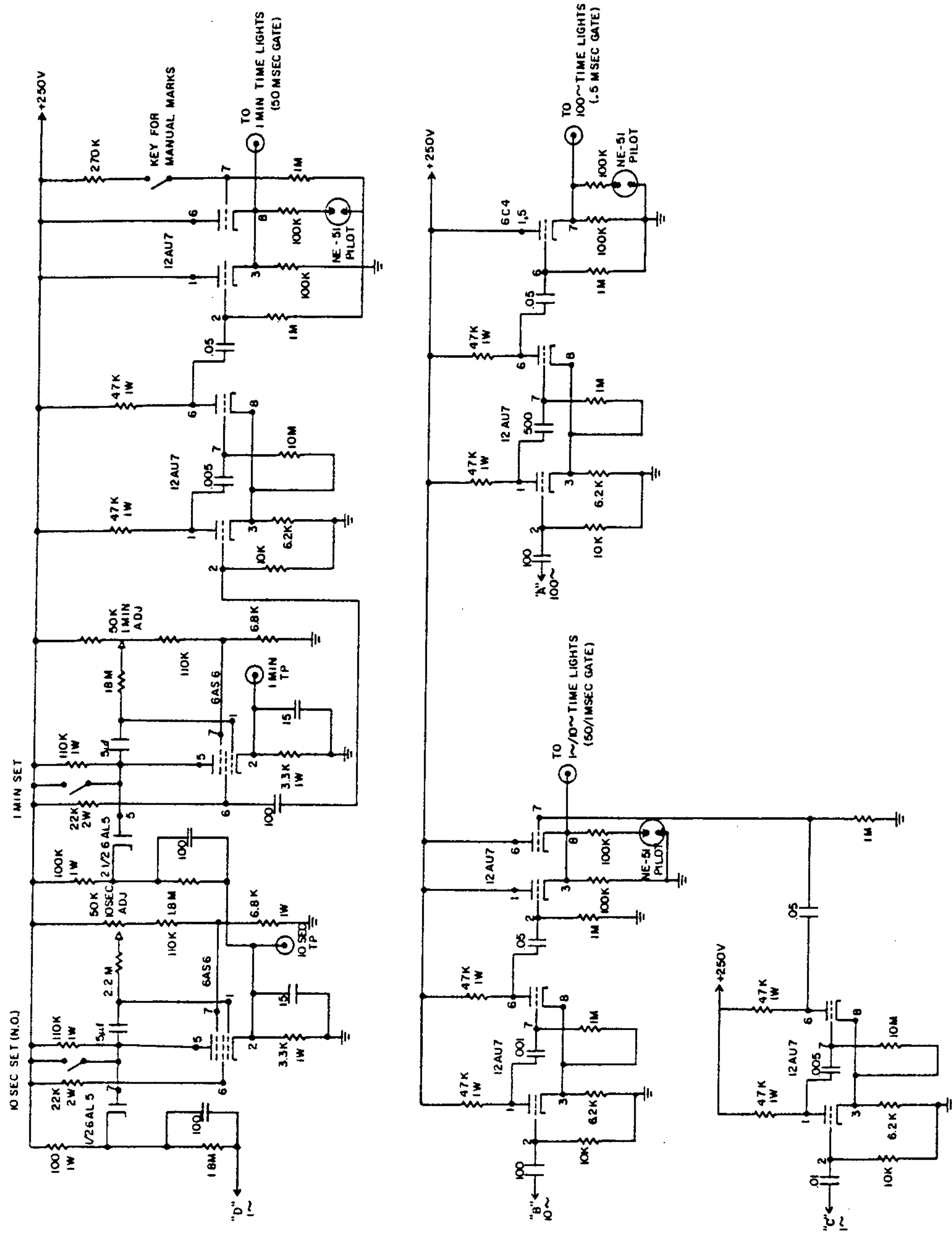



Figure C.5 Continued.

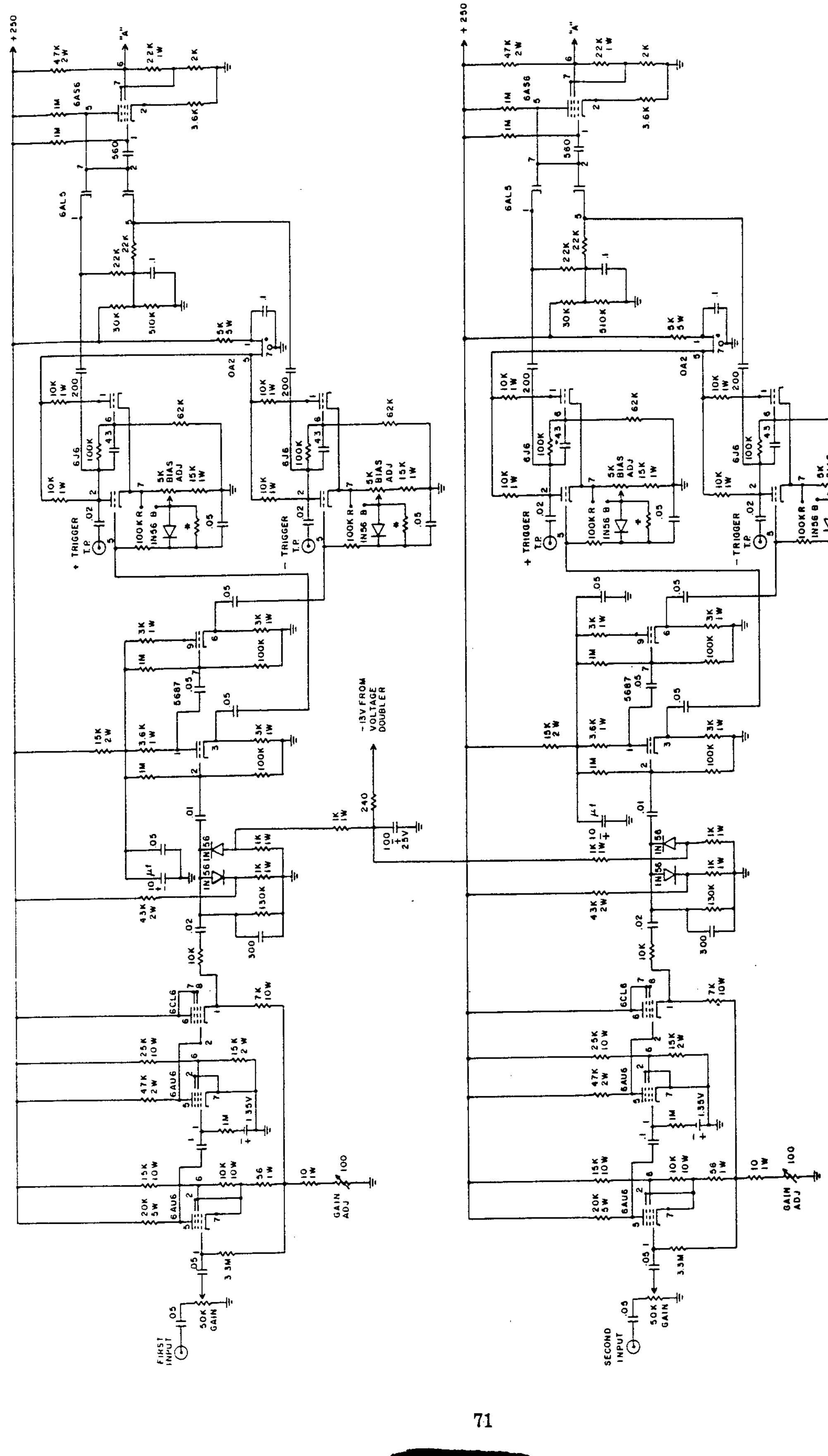


Figure C.6 Area gating circuit (see Block M8, Figure C.1).



[redacted]

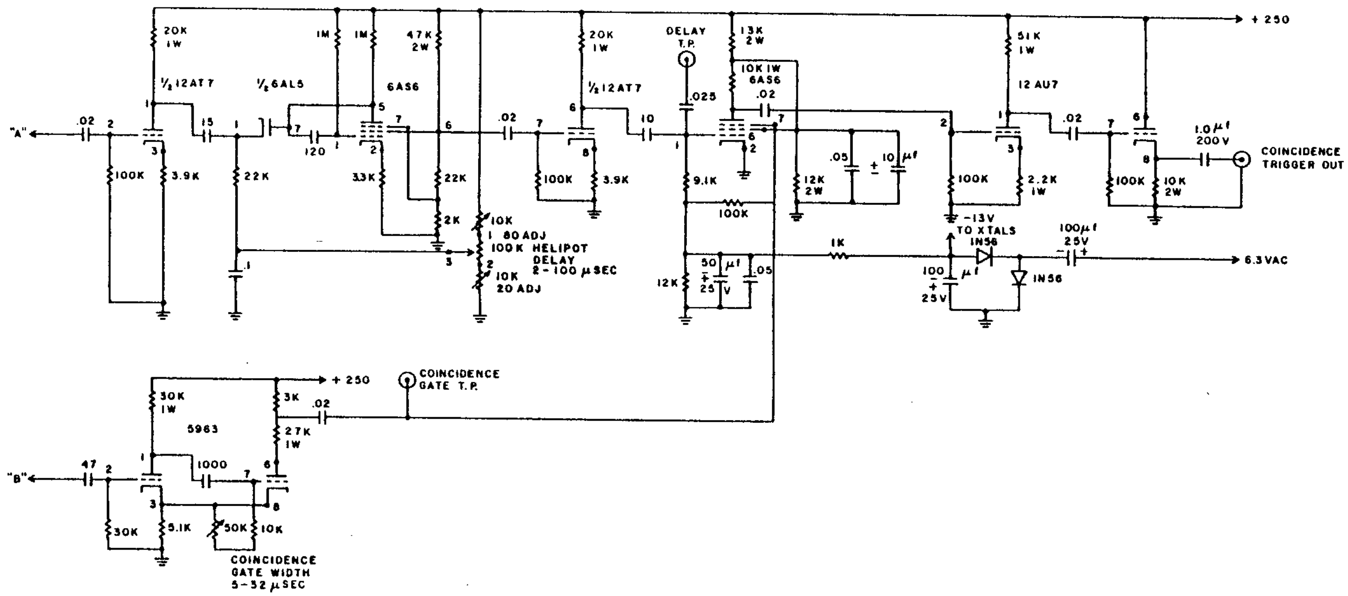



Figure C.6 Continued.



[redacted]

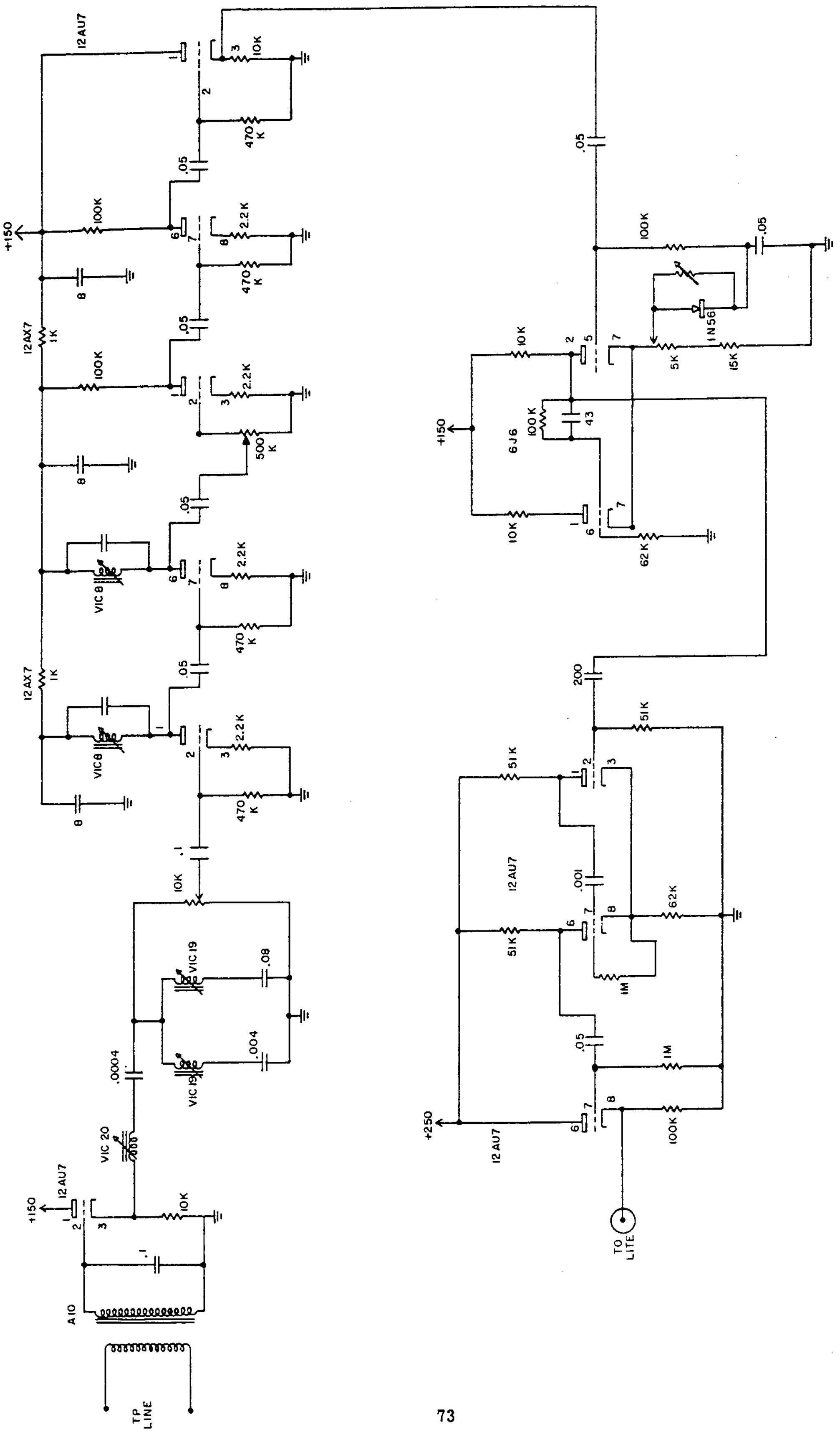



Figure C.7 Telephone receiver (see Block M0, Figure C.1).

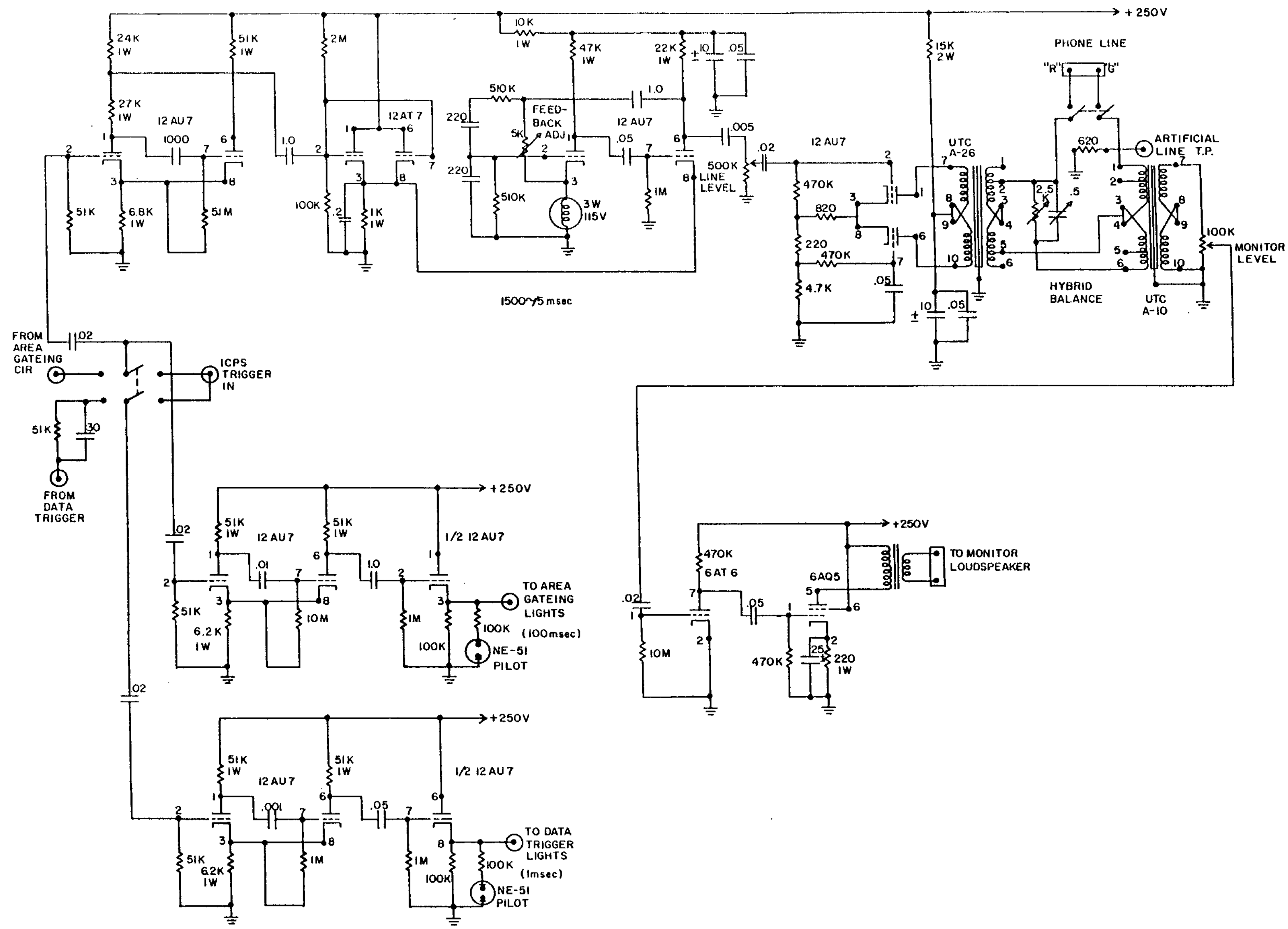



Figure C.7 continued. Telephone transmitter and marker light flasher (see Block M9, Figure C.1).

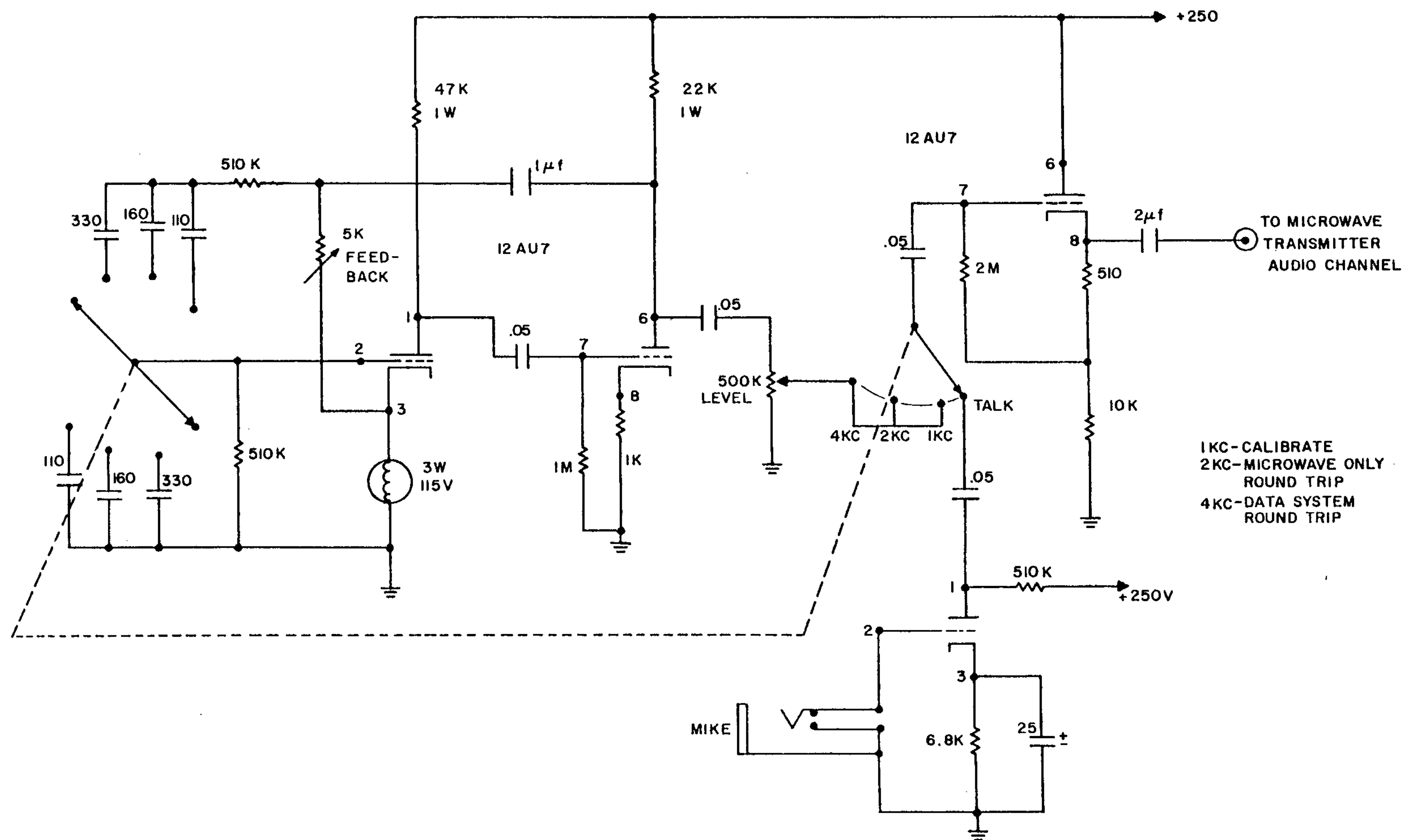



Figure C.8 Transmitter, slave station, remote control (see Block M 10, Figure C.1).

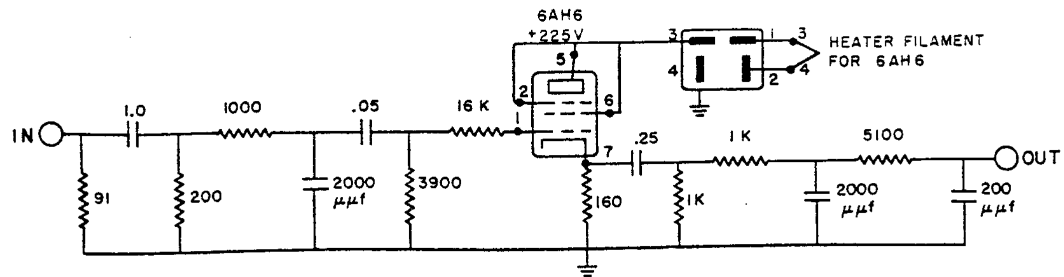
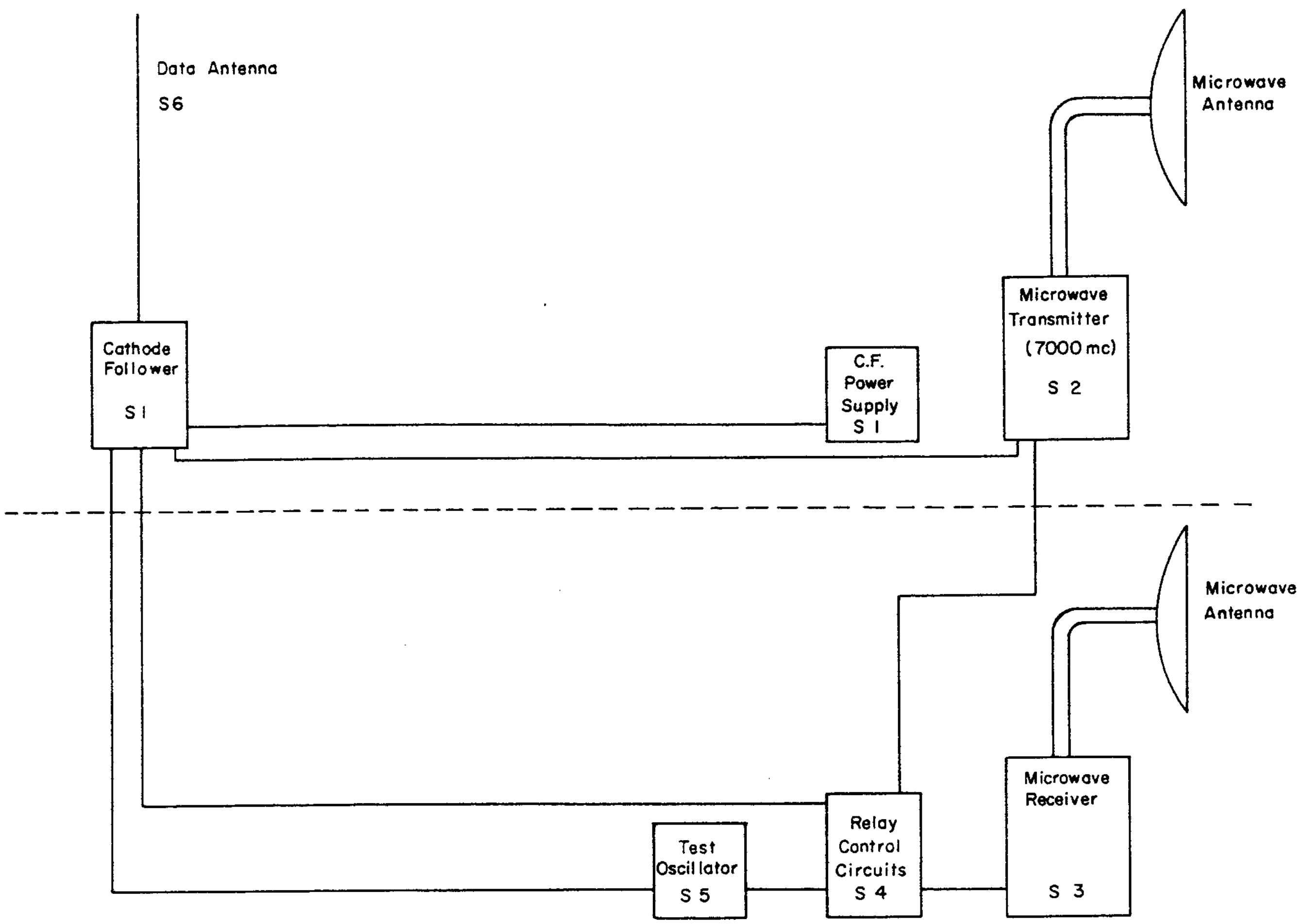



Figure C.9 Data filter (see Block M 13, Figure C.1).




| Block No. | Equipment | Figure No. |
|---|---|---|
| S 1 | Cathode follower | C.2 |
| S 2 | Raytheon Mfg. Co. KTR 1000A (R) transmitter | |
| S 3 | Raytheon Mfg. Co. KTR receiver | |
| S 4 | Relay control circuits | C.11 |
| S 5 | Hewelet Packard 650A test oscillator | |

Figure C.10 Slave station block diagram. Equipment above broken line for pulse reception and relay to master station. Equipment below broken line used for calibration and round trip measurements.



[redacted]

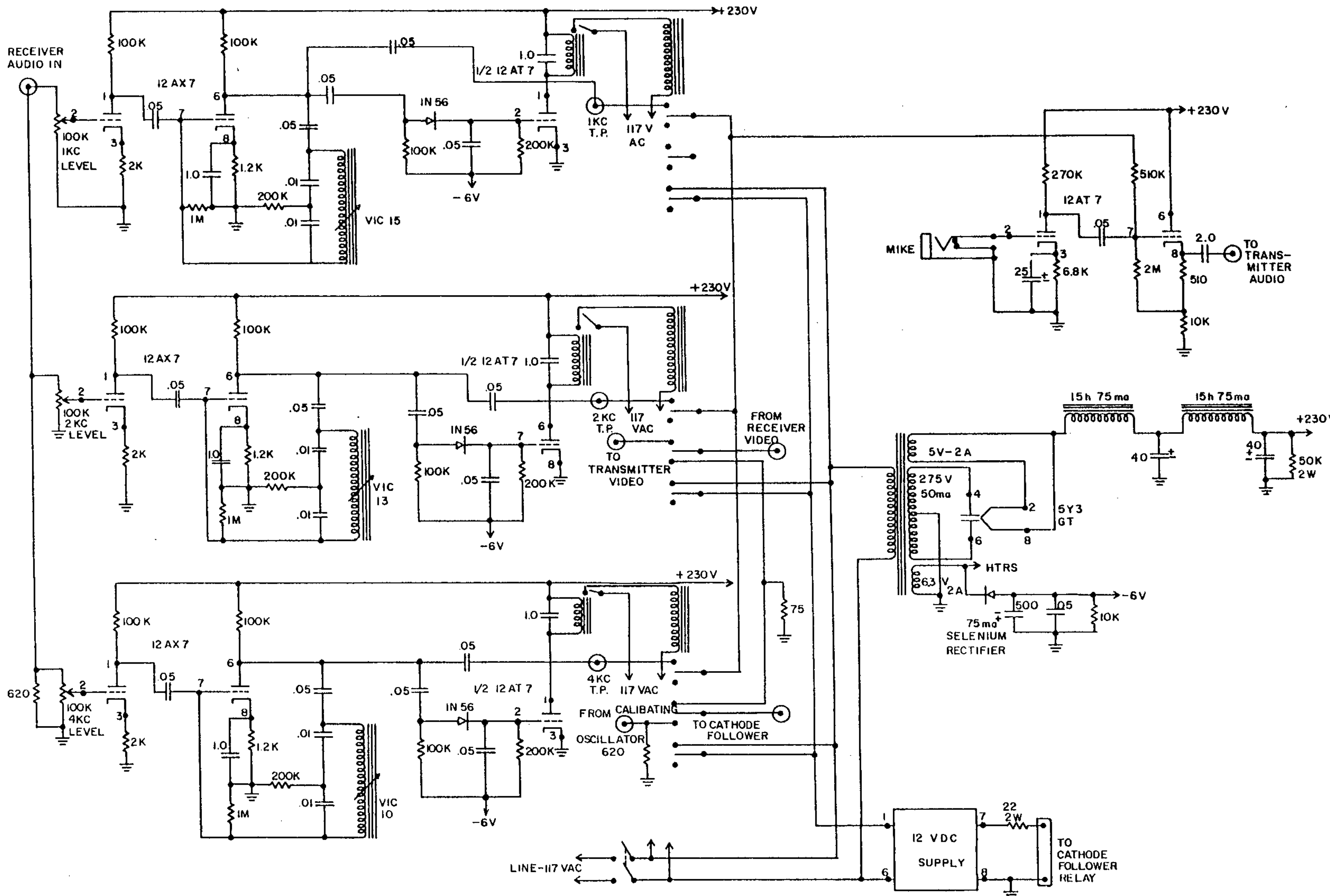



Figure C.11 Receiver, slave station, remote control (see Block S 4, Figure C.10).



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